

*A handbook of
chemical engineering*
George Edward Davis

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A HANDBOOK
OF
CHEMICAL ENGINEERING

ILLUSTRATED WITH WORKING EXAMPLES
AND
NUMEROUS DRAWINGS FROM
ACTUAL INSTALLATIONS.

BY

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A HANDBOOK
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VOL. II.

CHAPTER I.

THE APPLICATION OF HEAT AND COLD.

Nature made a beginning for us in the chemical industries. In hot climates the existence of natrona lakes, borax deposits, beds of common salt and nitrate of soda, shows us the effect of solar heat in distilling the water from natural aqueous solutions. These may be called chance formations, being produced without the guiding power of man, but it is also well known that the evaporative power of solar heat has been known and utilised from time immemorial in the manufacture of salt from sea water.

The establishments where this process is carried on lie chiefly on the Mediterranean, where the fluctuation of tides being practically nil, allows of the laying out of evaporation works with a comparatively small capital expenditure. Sea-water contains roughly 3.5 per cent. of total solids, or 96.5 per cent. of water, and possesses a specific gravity of 1.025, so that one is able to see the large amount of concentration that is necessary to reduce it to brine strength, or 1.21 specific gravity. Practically eight parts of sea-water by volume will only produce one part of a very impure brine.

In the Salines on the Mediterranean an acre of evaporating surface produces, as the product of a working year, 40 tons of salt of a fair degree of purity, besides other crystalline products, which fall after the bulk of the salt has been removed, and if we work this out it will be found that the evaporation effected must be more than half-an-inch per day. Now an inch of rain is always roughly taken as 100 tons to the acre, so that the evaporation of half-an-inch of water over this surface per diem means the removal of no less than fifty tons of water.

But the atmospheric conditions are not always so favourable to rapid evaporation as the foregoing. At Hayling Island, near Portsmouth, we are told, salt-pans were at one time supplied with brine furnished from sea-water by solar evaporation, this brine being further evaporated by the use of coal. Ronalds and Richardson mention that in the solar pans of a quarter of an acre in extent, sea-water becomes brine in about seven days, but this information gives us no idea of the commercial value of the operation. The author's experiments lead him to believe that under the most favourable conditions at Portsmouth the maximum evaporation would not exceed 0·17 inch per diem in open air tanks, even if worked as described only during the four summer months. At this rate a quarter of an acre of salt tanks would only produce 180 cubic feet of brine every seven days in fine weather.

In a series of experiments made by the author in 1875, in St. Helens, the practical result of solar evaporation varied from 0·07 inch to 0·1 inch in 24 hours under favourable circumstances, an amount quite outside the region of practical application. Latitude does not always, however, determine the solar efficiency, as Bombay and Calcutta are not widely separated in latitude, and yet Conybeare gives the evaporation at the former place as 96 inches per annum, while at Calcutta he gives 180 inches as the annual rate of evaporation, which latter is practically half-an-inch per diem.

Some private information given to the author in 1890, respecting the Kali Salars on the west coast of South America, lying between the equator and 10° north of that line, will give some insight as to the extent of solar evaporation under the most favourable circumstances. On the Pampa where these Salars are situate the heat from the sun is very great both in summer and winter. The sea wind and the south winds are fresh, whilst the land winds are uncommonly hot and drying. The variation in the day and night temperature is extreme; on a summer's day the thermometer will stand at 38° C. (100° F.) in the shade, and at 60° C. (140° F.) in the sun, whilst at night it will descend to 2° C. (36° F.). In winter the average night temperature is 3° C. (37° F.) in the shade under cover, while when exposed to the air and wind it may fall one or two degrees lower. The sand and saline soil become heated to these temperatures, and the water in shallow basins or pools some six inches deep is heated up to 47° C. (117° F.) during a summer day, and then at night cools down to about 2° C. (36° F.). Under a thin crust of salt the temperature of the same water will rise to 60° C. (140° F.) in the sun, while under a covering of window glass it will rise to nearly the boiling point.

Water has a greater surface tension than saline solutions, and while in the Pampa of the Cordilleras fresh water has an evaporation of 1·4 inches per day when freely exposed to the solar influence in summer, and 0·97 inch in winter, the evaporation from a saline solution, such as exists in the Kali Salars, is about 0·6 inch per day, or 220 inches per year. This is equal to 60 tons of water per day over the surface of an acre.

This subject has been mentioned at some length, as solar evaporation is now a competitor with coal. The works of the Egyptian Salt and Soda Company in Egypt, where soap is made as one of the products, is effecting

the preliminary concentration of the spent soap lees entirely by solar evaporation, to fit them for the final stage of vacuum concentrating by multiple effect. In hot countries where coal is dear no system of evaporation is as economical as this. A pan built of concrete, seventy yards square and six inches deep, will serve for the evaporation of sixty tons of water per day. In a paper on the Assouan dam, read in 1903 before the Institution of Civil Engineers, in London, Mr. Fitzmaurice stated that the mean temperature at that place was 42°C . (108°F .) in the day, but the heat was often as great as 46°C . (115°F .). At night the mean temperature was 30°C . (86°F .), but 38°C . (100°F .) was often recorded. There were many fatal cases of sunstroke amongst the workers.

All the foregoing is very interesting, no doubt, but fortunately for the bulk of humanity, business is not generally carried on in noon-day temperatures of 140°F ., and for most purposes of heating a combustible has to be provided.

The chemical composition of gaseous fuels with their approximate heating power has been fully described on page 326, Vol. I., and the composition of British coals on page 265 of that volume, so that it is needless to travel over the same ground again, but there are some facts concerning these combustibles which deserve mention here.

Natural gas has a large sale in the United States, where, at the close of 1901, no less than 11,300 gas wells were producing, the natural product being distributed through 21,850 miles of mains, varying in diameter from 2 inches to 36 inches. It is usually sent to the consumer under a pressure of four ounces to the square inch, at which it is employed for domestic purposes, but for industrial purposes it is often marketed at much higher pressures. Four ounces to the square inch is equal to seven-tenths of an inch of water pressure. As a source of power natural gas stands at the head of the list for economy. The natural gas engine is used most extensively in the petroleum fields for pumping the petroleum from small producing wells. In many instances, the flow of natural gas from the upper strata above the petroleum-producing rock in the well is sufficient to supply a gas engine to pump a cluster of wells, numbering, say, up to thirty. It has also been supplying the power for a very large number of factories and operations in the territory known as the gas belt, and lately it has been extensively applied in creating the power by which the natural gas itself is compressed so as to enable a larger initial volume to flow through the existing pipes. Some of these compressors work up to nearly one thousand horse-power with an economy that enables 10 to 12 cubic feet to develop one horse-power hour. As a source of light, heat, and power, natural gas is extensively used, even in the household, where the introduction of the Welsbach mantle has made it more than popular. In an article on the Production of Natural Gas, by F. H. Oliphant, in the "Mineral Resources of the United States," 1901, it is stated :—

"Natural gas is a luxury in the household which, when once acquired, is most difficult to dispense with. Consumers who have learned its value and convenience are very loath to part with it, and even under the penalty of

additional compensation to the producer, they prefer to retain it rather than go back to the grosser methods of heating by the use of wood or coal." In this connection, the reader may refer profitably to the closing remarks on page 65 of Vol. I.

The value of the natural gas consumed in the United States in 1901 was twenty-seven millions of dollars, which, at the average selling price of 15 cents, or eightpence, per thousand cubic feet, is equal to one hundred and eighty thousand millions. Taking Pennsylvania alone, the natural gas production is distributed by 296 companies through more than 9,000 miles of piping, supplying nearly one-third of a million domestic fires, 82 iron and steel works, 80 glass works, and over 1,500 other industrial establishments. It has been stated on page 326, Vol. I., that natural gas has not been found in this country in quantity, but we scarcely know yet what time has in store for us. Sussex has for some years been considered a gas field, satisfactory explorations having been made at Heathfield, a village on the high ground between Tunbridge Wells and Eastbourne. The gas comes from the Kimmeridge clay at a depth of about 600 feet with a pressure of 150 lbs. per square inch, and consists of 94 per cent. of marsh gas and 3 per cent. of ethylene.

We may now leave the subject of natural gas, remembering always that should it at some future time be found in Great Britain in quantity, its use should by no means be neglected; it is quite as easy to burn as producer gas or coal gas, and its heating power is very much greater than either of them.

Solid coal is at the moment the general fuel, and, whether burned in this form or first converted into gas of any kind, it is to coal we have to turn for our source of heat. Considering the wasteful manner in which it is consumed in almost every industry, and particularly the chemical industry, one would suppose that the idea was prevalent that our coal supplies would last for ever. In 1816 the coal raised in the United Kingdom was 27 millions of tons, in 1855 it had risen to 64 millions, in 1892 the total production was 186 millions, while the year 1900 saw the enormous quantity of 225 millions of tons raised from the pits in the British Isles. This appalling figure is approximately distributed as follows:—

	Per cent.
Used in the iron, steel, and smelting industries	26
In steam-raising factories generally	19
Shipped to colonies and foreign countries	18
Used for domestic purposes	15
Used by steamers at sea	6
Gas and waterworks	5
Used in collieries, mines, etc.	5
Chemical works and salt works	3
Potteries, glass works, brick kilns, etc.	3
—	—
	100

The diagram shown by Fig. 1 illustrates more clearly than words can tell how rapid the development of our coal fields has been especially during the past thirty years, and it also shows us how important a part the development of railways has played in the matter, a fact which should teach us the importance of securing a cheap and well organised system of distribution for all our manufactures.

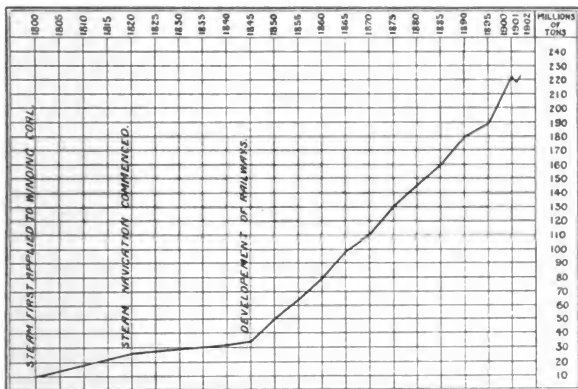


FIG. 1.—THE DEVELOPMENT OF BRITISH COAL-FIELDS.

The following diagram (Fig. 2) will also show the reason why Great Britain should use the best methods for economising her fuel. The dead black portion of the circle represents the proportionate area of the coal fields of the United States contrasted with the complete circle, which shows the entire coal fields of the world. The two small sectors are intended to represent, first, the coal fields of British North America, which is the larger of the two, whilst the smaller sector shows the proportionate size of the coal fields of Great Britain and Ireland, the cross-hatched sector setting out the remaining coal fields of the world. The world's production of coal, as lately as can be well ascertained, is shown in the following figures. Countries raising less than one million tons per annum have not been included.

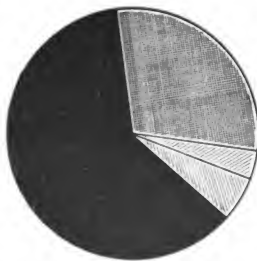


FIG. 2.—
THE COAL AREAS OF THE WORLD.

TABLE 1.

SHOWING THE WORLD'S PRODUCTION OF COAL.

United States (1901)	261,873,675
Great Britain (1901)	219,046,945
Germany (1901)	152,628,931
Austro-Hungary (1900)	39,029,729
France (1901)	32,301,757
Belgium (1900)	23,462,817
Russia (1900)	16,151,557
Japan (1900)	7,429,457
Australasia (1900)	7,353,225
India (1900)	6,118,692
Canada (1901)	6,186,286
Spain (1901)	2,747,724
South Africa (1900)	1,191,897*

It is difficult to fix a price, even an average price, for manufacturing coal, as so much depends upon quality, and more upon the cost of carriage from the pit to the consumer's works, and unless both of these quantities are accurately known, prices are useless for comparison. Take, for instance, the fuel bill of a large works known to the author. In one week there were delivered 100 tons at 4s. 1d., 50 tons at 5s. 9d., 50 tons at 8s. 6d., 150 tons at 7s., 50 tons at 7s. 11d., and 50 tons at 6s. In another works, coal was being delivered daily at 8s. 6d., 7s. 11d., 7s. 6d., 7s., 9s. 1d., and 10s., both in the same month of the year, but if some ordinary standard should be required for general purposes it might be safe to reckon good boiler slack at ten shillings per ton at the consumer's works in coal-producing centres, and at eighteen shillings per ton in non-producing centres. Thus the same fuel that can be purchased near Manchester at ten shillings per ton would cost eighteen shillings per ton at London or Plymouth. From some remarks that fell from the lips of the chairman of the Newcastle and Gateshead Gas Co., at a meeting of shareholders in 1903, it appears that the cost of the coal carbonised by that company during a period of seventy years averaged for each five years as follows: the prices being taken to the nearest penny:—

TABLE 2.

COST OF GAS COAL AT NEWCASTLE FOR A PERIOD OF SEVENTY YEARS.

Period.	Price per ton.	Period.	Price per ton.
1833-1837	5s. 0d.	1868-1872	6s. 6d.
1838-1842	5s. 2d.	1873-1877	12s. 3d.
1843-1847	4s. 8d.	1878-1882	8s. 1d.
1848-1852	5s. 3d.	1883-1887	6s. 6d.
1853-1857	6s. 2d.	1888-1892	8s. 5d.
1858-1862	5s. 5d.	1893-1897	7s. 3d.
1863-1867	6s. 7d.	1898-1902	10s. 4d.

* Including Natal and Cape Colony.

In burning solid fuel, such as ordinary furnace slack, burgy or boiler coal, or what is known as good round coal, the nature of the furnace in which the combustion takes place must vary with the requirements of the process. It must not be supposed by any means that the highest priced fuel, or rather a higher quality of fuel, will always enable work to be turned out either better in quality or more in quantity than by the use of a common quality. Much depends upon circumstances, but whatever quality of fuel be purchased, the ash and moisture contents must always be taken into account. Some steam raisers employ round coal, others use burgy, and others "slack," but it is very doubtful whether any correct figures of the cost of steam from these three sources have ever been worked out on the same boiler in actual practice, so as to serve as a guide as to what course should be followed. At least, the author has endeavoured to get some such figures from his numerous friends for the purposes of this work, without success.

The following experiments, however, made some years ago with a mechanical soda-ash furnace, will give us some insight into the question. Each trial lasted six days.

TABLE 3

SHOWING THE COST OF FURNACING SODA-ASH WITH VARIOUS QUALITIES OF FUEL.

	Nuts.	Burgy.	Slack.
Total weight of ash drawn	81·7 tons	73·2 tons	69·75 tons
Weight of fuel used	30·6 "	25·85 "	25·4 "
Price of fuel per ton	9s.	7s. 6d.	5s. 6d.
Fuel used per ton of ash	7·5 cwts.	7 cwts.	7·3 cwts.
Cost of ditto per ton of ash	3s. 4d.	2s. 7d.	2s.

In considering the foregoing table, it must be remembered that commercial considerations generally step in—it may pay better sometimes to burn a better fuel in order to obtain an increased output, notwithstanding that the cost per ton may be higher. If it is higher, the management should know by how much.

Coke may be considered as the next best known fuel, and it may conveniently be classified in three grades: gas-coke, bee-hive oven coke, and the third class produced in ovens from which by-products are recovered. Gas-coke is too well known to require description; it is extensively used in chemical works for heating purposes, where the presence of smoke would be detrimental, such as in concentrating acids and other solutions by over heat, in the drying of malt, the burning of limestone, and the production of carbonic acid gas. The contents in water and ash set its value at a proper figure, and should always be ascertained by those who use it. In the next table (4) are given some particulars of samples that have passed through the author's hands, Gas-coke made from cannel coal always re-

quires special investigation. The second quality of coke, viz., that made in bee-hive ovens without recovery of the by-products, is the ideal smelters' coke. Whereas gas-coke is soft and would always break down under a moderate burden, oven-coke is bright and hard, and will stand a great crushing weight. Moreover it is usually dry, rings when tapped, and possesses a high plumbago lustre, being slaked with a jet of water within the oven itself. There is no doubt that for many purposes coke made in this way is much superior to some of the coke made in ovens from which the by-products have been recovered, as the softer parts get burned away when the oven has reached its maximum temperature, an operation that never takes place in recovery ovens charged with washed and wet dross.

The coke from recovery ovens is mostly dull and black, although there are exceptions. It is pushed out from long rectangular ovens in a red-hot state and slaked outside the oven, which causes this dull appearance. Coke of this grade is hard, some of it very hard, and for smelting purposes or for use with forced draught of any description is quite as good, *ceteris paribus*, as the best oven coke made in bee-hives without recovery of the by-products.

The following table will show some of the characteristics of the varieties of coke at present in the market :—

TABLE 4.
SHOWING THE CONSTITUENT MATTER OF COKE.

	H ₂ O.	Ash.	S	C.
Gas coke	9·7	7·2	1·19	83·1
" "	11·1	5·4	0·72	83·5
" "	3·8	5·6	0·66	90·6
" "	9·6	7·8	0·33	82·6
Bee-hive coke	2·2	4·7	0·62	93·1
" "	6·9	11·5	0·39	81·6
" "	0·7	4·2	0·51	95·1
" "	4·7	5·8	0·55	89·5
By-product coke	4·0	9·0	0·27	87·0
" "	8·0	10·4	0·55	81·6
" "	4·4	16·1	0·38	79·5
" "	9·7	12·2	0·46	78·1

The residue, after deducting ash and moisture, may, without sensible error, be called carbon. There is still hydrogen and nitrogen there, with, in most cases, traces of phosphorus and arsenic, but the quantity is too small to effect any influence from the furnaceman's point of view. The numbers representing carbon may be found in the last column of the table.

The ironfounders of the States are very careful in the selection of their coke, and a few firms in this country are just as particular. As an instance of this is given the specification drawn up by Mr. C. Scott, chemist of the J. I. Case Threshing Machine Co., of Winconsin, which may serve as a pattern at home.

Specification for Coke.—“Under this specification we desire a good, clean 72-hour coke, as free as possible from coke dust and cinder.

The percentage of wall-coke, known as ‘black heads,’ must not be greater than that usually found in ‘Selected’ No. 1 foundry coke.

The coke should be of the massive form, and reasonably free from small particles, *i.e.*, granulated coke.

Structure is an important feature, and will be considered when purchasing coke.

The structure of a perfect 72-hour coke should, according to theory, be made up as follows :—

	Per cent.
Cellular structure	56·00
Coke structure	44·00

We do not expect to get a coke with an ideal structure, but we do insist on a coke with a proper structure for cupola work.

Our castings are made according to specifications, and, as the iron is mixed by analysis, it is absolutely necessary that the coke be low in sulphur and phosphorus.

Well washed coke should not exceed the amount of sulphur herein specified.

When a car of coke is received it will immediately be sampled by an experienced man, who will select two average samples (10 pieces) of the coke from different parts of the car, and these two samples will be sent to the laboratory for a check analysis.

The coke will be accepted if it comes within the following limits, *viz.* :—

	Per cent.
Moisture should not exceed	1·50
Volatile matter should not exceed	3·50
Fixed carbon must be above	86·00
Sulphur must not exceed	0·75
Ash may range from	5·50 to 11·50

Coke will be rejected which shows on analysis :

	Per cent.
Sulphur, more than	0·85
Phosphorus, more than	0·05
Fixed carbon, less than	85·00
Ash, less than	5·00

These limits will be strictly adhered to, and no concessions made in any case.

Note.—The Heinrich method is used for all determinations in the proximate analysis of coke, except sulphur, which is determined by Eschka's method.

When sulphur is included in an analysis it is to be understood that the volatile matter carries one half and the fixed carbon the other half of the per cent. due to this element.

The two following analyses of a light and a strong coke will give a good idea of our method and statement of a coke analysis. Both of these cokes are within the limits of the specification.

	No. 1. Per cent.	No. 2. Per cent.
Moisture	0·33	0·49
Volatile matter	2·25	1·31
Fixed carbon	90·54	87·46
Sulphur	0·60	0·72
Ash	6·28	10·02
Structure, cells	52·94	50·04
Structure, coke	47·06	49·96
Specific gravity	1·697	1·890
Heat units (C.H.U.)	7,522	7,187

No. 1 is a light coke with medium porosity, and will give a quick, intense heat.

No. 2 is a strong coke and will hold up a heavier burden of iron; the porosity is lower—*i.e.*, the coke is more dense—consequently a stronger blast is required.

A strong, heavy coke will give a steady, continued heat."

Liquid Fuel.—A few words may now be said upon liquid fuels and their application to the purposes of raising heat. In times of great fuel scarcity, such as occurred during the coal strike of 1893, many manufacturers have endeavoured to rely upon liquid fuel of various kinds as a substitute for coal. Some of these attempts have lasted longer than others, but in every case that has come under the author's notice, the users have only been too glad to discontinue the use of liquid fuel at the earliest possible moment. In several cases known to the author the operation was conducted entirely by rule of thumb, and in a most wasteful manner, so that it is by no means surprising that the process should be thrown out of use by those who had the bill to pay.

It must not be supposed that the discontinuance of the use of liquid fuel was in any way due to its failure from a physical or mechanical standpoint. It is a fiscal question entirely, and when heat can be raised more cheaply from liquid fuel than with coal, manufacturers will revert to the former. It is, therefore, necessary to know the economics of these substitutions.

In Great Britain at the present time the only liquid fuels available for large scale heating are—gas-tar, coke-oven, and blast-furnace oils, and coal-tar creosote, though in other countries crude petroleum and the semi-liquid astatki, or petroleum residue, may form a subject for serious consideration. Crude petroleum, consisting of 84 parts (by weight) of carbon, and 14 parts of hydrogen, is a very good substance for comparison. If we follow the methods described on page 266 of Vol. I., we shall find that a substance of this composition gives a theoretical heating power in Centigrade heat units as follows:—

	%.	Per lb. of oil.			C.H.U.
Carbon	84.0	0.84	×	8080	= 6787
Hydrogen	14.0	0.14	×	34462	= 4824
					<hr/> 11611
Less water		1.26	×	606	<hr/> 763
					<hr/> 10848

In actual practice, Mr. W. L. Watts, of the California State Mining Bureau, says that the relative value of petroleum and coal, of heating values of 10,200 and 6,684 C.H. units respectively, is 2.5 barrels of oil to one ton of coal of 2,000 lbs., for heating furnaces, and for steam-raising purposes from three barrels to four barrels of oil are equivalent to one ton of coal of the aforesaid quality. Rough estimates of comparative value over short periods are of but little value. It is the author's experience that it requires some considerable time for ordinary workmen to become accustomed to the necessary detail of liquid fuel burning, as it is hardly fair to the combustible to make comparative trials with it before the firemen have attained a high degree of proficiency.

Coke-oven oils, blast-furnace oils, coal-tar and coal-tar creosote contain a considerable proportion of oxygenated compounds, so that their heating power is less than that of petroleum, but as they may be burned with greater air economy than solid fuel it is usual in practice to reckon them as equal to twice their weight in "slack," and this estimate is fairly exact. Slack with a heating value of 6,000 C.H.U. per lb., utilising 70 per cent. = 4,200 C.H.U., while a pound of petroleum of a heating value of 10,000 C.H.U., utilising 80 per cent. of the heat, gives 8,000 C.H.U. for each pound, so that

$$\frac{8000}{4200} = 1.9$$

theoretically is the relative value of petroleum and slack.

Few have had the opportunity of testing the relative heating values of gas, coke, coal, and liquid fuel on a sufficiently large scale and over any extended period, so that the following conclusions arrived at by the author in 1886, after more than twelve months' continuous work, may serve as a guide to the relative heating values of these combustibles. The following were equal values:—

- One thousand cubic feet of gas.
- Fifty pounds of good slack.
- Sixty-seven pounds of gas-coke.
- Three gallons of creosote or tar.

The gas was coal-gas, from which the benzol, toluol, and xylol had been extracted; the coke was ordinary gas coke, made in the usual way in fire-clay retorts, from a good gas coal; the coal was ordinary Silkstone slack; while the liquid fuel employed was the creosote obtained from the tar produced in the foregoing process of gas making. The gas was employed in heating the retort ovens, steam boilers, tar stills, and light oil stills, so that the heating operations were very varied, and enabled a good general comparison to be made.

So far we have only considered carbonaceous combustibles, but chemical requirements are by no means limited to these substances. The combustion of the sulphur compounds of the metals is quite an ordinary process of chemical manufacture, and the heat given off by combustion is nowadays utilised as completely as it that heat had been produced by the burning of carbon or ordinary fuel. This brings us to what may be called the introduction to our subject proper—the nature or object of the combustion.

The instance mentioned in the last paragraph as the combustion of metallic sulphides has generally for its primary object the preparation of sulphur dioxide, but it also results in the preparation of the mineral for the extraction of the metallic basis and the utilisation of the heat of combustion. The aim of all chemical processes should be the utilisation of everything, and the avoidance of waste. It is often cheaper to prevent waste than to attempt to utilise a waste product. This can be better illustrated from a case in actual practice, which leads us also to the consideration of the operation where the object of the combustion is, primarily, the mere production of heat. In the carbonisation of coal for the sake of by-products, with which the author was connected from 1883 to 1887, the retorts were designed to be heated with the debenzolated gas, and provision was made for the waste heat escaping from the retort settings to pass under a steam boiler for its thorough utilisation. While this disposition was worked there was only sufficient gas to keep eight fires going out of the 22 ovens, and the water in the steam boiler never rose to a temperature of more than 108°C . (5 lb. steam) notwithstanding all the damper regulation and other attention given to it. The boiler was simply a water heater. Moreover, a certain amount of coke was also used on each of the eight fires, while the remainder, 14 in number, were fired entirely with coke, as were also the remaining steam boilers and stills. When it was found that the practical requirements were so much more than the theoretical figures, attention was paid to the development and improvement of one fire, and after a few days of experiment it was found better to work with an almost closed damper to each oven, and to reduce the gas consumption to just that quantity that would keep the oven hot, than to burn the gas extravagantly and attempt to catch the heat leaving the oven, even by the extensive surfaces of a thirty feet steam boiler. Under the altered conditions, the volume of gas that formerly barely sufficed to heat eight ovens, now sufficed for 22 ovens, three steam boilers, and two tar stills, no coke whatever being used to assist.

The nature or object of combustion in most instances is something akin to the foregoing—plant and appliances generally have to be heated, steam has to be raised, materials have to be calcined, roasted or fused, solutions require heating for evaporation or distillation, or minerals require smelting for the winning of a metal from them. The complete plants in which the foregoing operations take place are very varied in design, and illustrations or descriptions of even a title of them would more than fill these volumes, so that one is constrained to follow some general line which may sufficiently set out the principles underlying the subject so far as it affects the designing of chemical apparatus.

The furnaces employed for burning all ordinary kinds of solid fuel are simple in the extreme, consisting in the main of a chamber to contain the fuel, which rests upon fire bars of various patterns. In most chemical works these fire bars are ordinary wrought bars of square or rectangular section, varying in size from one inch square to two inches square, according to the dimensions of the furnace, but for steam boilers and such installations as rectifying glasses and many minor purposes in the finer chemical processes, cast-iron fire-bars of various patterns are very largely used. In firing steam boilers the fire is kept very thin, so that though there is heat enough in the zone of combustion to melt copper, the bars are as a rule cool enough to prevent the ashes from sticking to them in the form of clinker, with but moderate "scurfing" on the part of the attendant. In ordinary furnace work, the fires are much thicker, and there is a greater body of heat to contend with, so that the bars are much hotter in this case than in that of steam boiler fires.

As instances of the area of firegrates and the cubic capacity of high power furnaces, no better examples can be selected than those necessary to heat the revolving furnaces of the Leblanc soda industry, or the same style of furnace which is now employed for decarbonating the carbonate of soda by heating it with oxide of iron in the Löwig process as now carried on at Warrington and Northwich. These furnaces are made of various sizes, some of very large capacity, and others small, but the medium size is generally preferred, no doubt with very good reason, if tear and wear be at all considered.

In these revolver fire-places the grate area varies from 50 to 80 square feet and the cubic capacity of the furnace, reckoned to the top of the fire bridge, varies from 150 to 300 cubic feet, the whole of the products of combustion having to pass through an opening into the revolver having an area varying from seven to ten square feet, and in some cases more than this. In a revolving furnace, well known to the author, the fire-grate area was 50 square feet, the cubic capacity of the fire-place measured 200 cubic feet, while the revolver inlet was 10 square feet. In this fire-place 73 tons of fuel were burned each week of 168 hours, which is 20 pounds per square foot per hour. This heat was sufficient to work up 69 charges of salt-cake per week, each charge weighing 42 cwts., or 10 cwts. of fuel per ton of salt-cake.

The foregoing figures will give the reader some idea of the working details of a furnace of large capacity. Furnaces wherein the products of combustion come in contact with the materials that are being furnaced are called "open" furnaces, and the "revolver" is one of them. Before the introduction of the revolver, such work was carried on in hand furnaces, of which a drawing is shown in Fig. 3. These furnaces, or suitable modifications of them, were largely employed for black-ash making, salt-cake roasting, the drying and carbonating of soda-ash, and, in fact, for any purpose where contact with the fuel gases could not harm the product. In making black-ash, such a furnace as the foregoing would deal with about 20 tons per week of salt-cake, consuming 12 tons of firing slack upon the bars. As the fire-grate area is 16 square feet, this amounts to a combustion of 12 lbs. per

square foot per hour. In most cases, however, it is not necessary to have the furnaces so large in grate area, as it is certain that open furnaces will burn 20 lbs. of fuel per square foot of grate surface per hour, and with a keen draught often much more than this. When the presence of smoke in the fuel gases tended to interfere with the process, either by choking the condensers as in the open salt-cake roaster, or by preventing oxidation as in the calcination of copper ores with salt, the difficulty was overcome by a change of fuel. It was thus that coke came to be the normal fuel in the open salt-cake furnace, and gas the fuel of the copper calciner.

Up to the year 1876, the open furnace was adhered to in many quarters, as against the "close" or "muffle" furnace, on account of the economy in fuel. The old open salt-cake furnace produced about 40 tons of salt-cake weekly, and consumed about three cwts. of coke for the roaster fire, and three cwts. of slack for the pot fire per ton of salt-cake produced, while the muffle furnace consumed from 13 cwts. to 16 cwts. of total fuel per ton, and the result was no better when Siemens' gas was used as fuel. At the Hardshaw

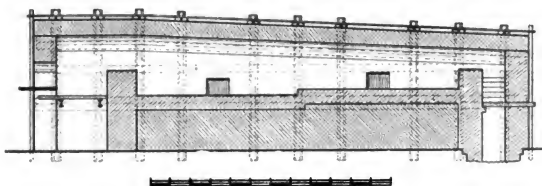


FIG. 3. - ORDINARY FORM OF OPEN FURNACE.
(A Black-Ash Furnace.)

Brook Works, in St. Helens, during the last six months of 1874, 2,694 tons of salt-cake were produced by the expenditure of 1,846 tons of burgy in the producers, or 14 cwts. per ton of salt-cake. At the Weston Works of the Runcorn Soap and Alkali Co., the fuel consumption for salt-cake making during 1875 was 13½ cwts. per ton. Since that time, however, the muffle furnace has been greatly improved, and the open furnace is now to be found only in the most antiquated establishments. The improvement was introduced by Deacon, of Widnes, who obtained a patent in 1876 for a plus pressure furnace, that is to say, a furnace in which the pressure outside the muffle was greater than the pressure of the gases inside it. This was brought about by sinking the fire-place in the ground. At first the fire-place and ashpit were sunk about 12 ft., and this is the practice in some works to-day. It is the author's practice, however, not to sink the ashpit so deeply, as he has found that a distance of 4 ft. or 5 ft. is quite sufficient for the level of the ashpit floor below the working floor. The full details of a furnace of this kind, designed by the author, may be seen in Fig. 4.

In the drawing may be seen the fireplaces which act really as miniature gas-producers; and the combustion is regulated entirely by the dampers,

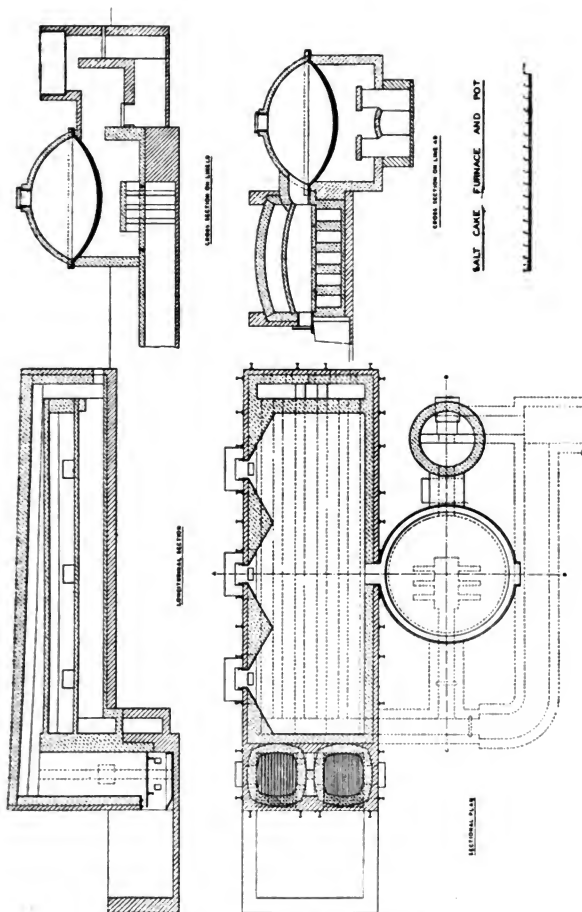


FIG. 4. - PLUS-PRESSURE MUFFLE FURNACE.
(The Author's Design.)

so that the rate at which the fuel is burned per square foot per hour may be quite abnormal. A furnace of the pattern illustrated possesses a fire-grate area of 21 square feet, and, as nearly 30 tons of fuel are burned per week upon that surface, this amounts to 19 lbs. per square foot per hour. This is the author's design, but had the grate area been 32 square feet as in some furnaces, the amount of coal per square foot per hour would only have been 12 lbs. The economy of these furnaces is, however, very striking, as a well-designed furnace will turn out over 84 tons of salt-cake per week, so that the consumption of fuel is about seven cwts. per ton of salt-cake, as against 14 cwts. on the old system. When all the flues are properly proportioned, the products of combustion leave the furnace with a percentage of oxygen rarely exceeding 2.5, and as these gases are made to heat the salt-cake pot the further admission of air at the proper point causes them to complete their work with as little as six per cent of oxygen in the final exit gases. The waste gases from the salt-cake pot are made to pass under a lead-lined, cast-iron heater, in which the acid is heated to a high temperature before its admission into the salt-cake pot, and this not only further utilises the heat of the fuel, but adds to the longevity of the pot, and tends to increase the output of salt-cake.

Copper calciners may be constructed in the same manner as the plus pressure salt-cake roasters, but the general plan is to keep the fire-bars on a level with the working bed, and to retain the ashpit paving upon the ground floor. In this latter form the fire-grate area need not be so large as on the plus pressure system, in fact, a fire-place of 16 square feet is quite large enough to heat a furnace having an outside measurement of 50 feet by 14 feet, and such a furnace will consume fuel at the rate of 14 lbs. per square foot per hour. In these muffle furnaces the combustion must be allowed to proceed as gradually as possible; too great an excess of oxygen should not be allowed in the first instance. If too much of the combustion is done at the fire-place, the front portion of the furnace will soon be burned out, while the latter end is but insufficiently heated. This is specially to be guarded against in firing with gaseous fuel. The United States furnishes us with some examples of very large furnaces, and considering the high temperature at which the products of combustion leave the flues of short furnaces, the longer flue of those in the States have much to recommend them. The Brown straight hearth roasting furnace is built of different lengths, varying from 100 ft. to 200 ft. and 10 ft. wide, while the Jackling roasting furnace has a roasting bed 200 ft. long by 12 ft. wide. The Wetthey furnace has also a roasting hearth 120 ft. long. In that country also, the McDougall furnace is a vertical brick cylinder encased in iron, 14½ ft. in diameter, with six hearths placed one above the other, as in the English but smaller type.

In using gas as the combustible it has first to be manufactured. The plant in which it is made is generally called a "producer," of which there are many forms. It must not be forgotten, however, that the fire-place of a plus-pressure furnace is, in reality, a miniature gas producer, and as the gases leave it at a high temperature, and pass along the training flues of the furnace without becoming cooled in the same way as ordinary producer gas

is cooled, and, moreover, as each furnaceman attends to his own producer, or fire, to be more correct, the special advantages of a separate gas-producer should be clearly made manifest before any such installation is decided upon. It is now upon record (page 14) that a muffle salt-cake furnace, fired with Siemens' producer-gas, consumed 14 cwts. of burgy per ton of salt-cake produced, while the same weight of salt-cake made in the plus-pressure furnaces requires only seven cwts. of slack. This is *prima facie* evidence that a considerable loss of heat takes place somewhere in the first case, while in the second case the figures tend to show its much more profitable utilisation.

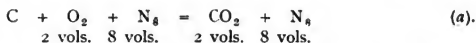
The action of the gas-producer is precisely the same as that of the fire-place of the plus-pressure furnace. The fuel is partly burned by a current of air sufficient only to convert the carbon into carbon monoxide, and the heat so generated causes a more or less partial distillation of the superstratum of coal, the products of which mix with and pass on with the main current of gas.

In the earlier producers an air current alone was employed for combustion, but, later on, it was found that the introduction of steam showed important advantages. Part of the fuel was in fact burned with the oxygen of steam instead of the oxygen of the air, and the equivalent of hydrogen was liberated, to be burnt again to water at the correct moment. In the early days of steaming producers a very common error was propagated in supposing that the actual amount of heat generated was augmented by the admission of steam into the producer, many of those who rushed into print forgetting that the water molecule absorbed heat in becoming split up into its constituents. There was, however, *prima facie* evidence to the practical man that the admission of steam to furnace fires did increase the heat, though really the observations bore another interpretation. An experiment of the author's may perhaps make this matter clearer:—

An open salt-cake furnace was designed to work with coke as fuel, and to turn out three tons of salt-cake per shift of twelve hours. Owing to the scarcity of coke anthracite coal was employed, with the result that a maximum of 25 cwts. of salt-cake was drawn per shift. The heat was intense in the fireplace, its life was seriously menaced, and the clinkers fused fast to the fire-bars, but, nevertheless, the heat in the furnace itself was not high enough to allow more than 25 cwts. of salt-cake to be furnaced. An experiment was then tried of placing a perforated pipe for steam underneath the fire-bars, so that a considerable quantity of steam should pass through the fire-bars with the entering air. The trial was eminently successful, the furnace was immediately filled with flame, and the required quantity of salt-cake was easily furnaced in the specified time. Moreover, the heat in the lower portion of the fireplace was sensibly reduced and the clinkers no longer adhered so tenaciously to the bars. Most of those who witnessed the trials came to the conclusion that the total amount of heat had been augmented, whereas the true explanation was that the heat immediately above the fire-bars had been absorbed during the conversion of the steam into carbonic oxide and hydrogen, and these when free from the fireplace

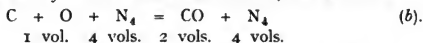
were converted by air oxidation into carbon dioxide and water. The heat of combustion was not increased—it was transferred.

In the ordinary combustion of carbon in air the oxidation takes place as follows :—



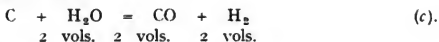
and as the thermal effect of one part by weight of carbon is 8,080 Centigrade heat units, the twelve parts of carbon entering into the reaction will yield 96,960 C.H. units.

If the carbon is merely burned to carbon monoxide, the reaction is :—



and as the thermal effect of producing carbon monoxide from one part by weight of carbon is 2,473 C.H.U., the twelve parts of carbon will yield 29,676 Centigrade heat units.

Steam does not react upon coke unless the latter is at a red heat, so that extraneous heat is required whenever coke or carbon is to be burned in a current of steam. One part by weight of hydrogen when burnt with oxygen yields 34,462 C.H.U., and at least this heat is necessary when the reaction has to be reversed. Therefore, in burning carbon in a current of steam, to carbon monoxide and hydrogen, heat is given out by the formation of the carbon monoxide and absorbed by the decomposition of the steam. The chemical reaction is :—



and the thermal effect is as follows :—

18 parts of water absorbing by decomposition	.....	68,924 C.H.U.
12 parts of carbon burning to carbon monoxide	.....	29,676 „
Deficiency, or heat to be supplied	.....	39,248

It is upon these three reactions that the operations of the gas producer are founded, the influence of the nitrogen in absorbing a portion of the heat produced being neglected in the equations. If we have too much air present in proportion to the carbon, the combustion will proceed to completion as in equation (a). If we so limit the supply of air that nothing but carbon monoxide is formed, we shall proceed according to equation (b), and the carbon monoxide will be diluted with the whole of the nitrogen present with the oxygen at the moment of its combustion. When, however, carbon is burned in a current of steam, according to equation (c), two volumes of steam produce four volumes of combustible gas (commonly called water-gas) and these are free from any intermixture with nitrogen.

Originally, “producers” were designed to work according to equation (b), and “water gas” producers according to equation (c). Very many, indeed, have been the modifications introduced into the construction of both these series, with which, however, it is not the author's intention to

deal, as it is quite sufficient to understand the principles that have led up to the modern perfected producer.

The producers working mainly in the direction of equation (b) gave out a certain amount of heat by the partial combustion of the carbon, amounting to 2,473 C.H. units per pound, and the greater part of this heat was lost or dissipated from the gas-mains before reaching the furnaces where the gas was finally burned. As the total heat produced by the combustion of a pound of carbon is 8,080 C.H. units, it will be recognised that 2,473 units must be 30 per cent. of the whole.

The metric system gives us the heat of combustion expressed in *calories* per kilogramme of the combustible, each calorie being the heat necessary to raise one kilogramme of water through 1°C . It will be evident that the calorie stands to the B.T. unit as 3.96 to 1.0 ($180 \times 2.2 \div 100$) in actual thermal capacity—roughly it is often taken as 4.0 , but it follows that if the unit weight of water taken to receive and measure the heat evolved by the combustion of a similar weight of the combustible, or an aliquot portion of it, the metric figures will apply to all weights of any denomination. Thus a pound of carbon will heat 14,544 pounds of water 1°F . by its perfect combustion, or 8,080 pounds by 1°C ., and a kilogramme of carbon will also heat 8,080 kilogrammes of water 1°C . under similar conditions. The author would like to see the Fahrenheit thermometer scale abolished, but while it exists amongst us, its relation to other scales must be pointed out. For similar weights, the only relationship to remember need be $100^{\circ}\text{C} : 180^{\circ}\text{F}$.

The temperature of combustion may be readily calculated by the method explained on page 268 of Vol. I., and by it we may follow what takes place as represented in equations (a) and (b) on the foregoing page. If the combustion is only partial, as shown by the reaction (b), a temperature of $1,600^{\circ}\text{C}$. will be reached, and this heat will not do much damage to good fire-bricks; but if the carbon is allowed to burn to carbonic acid gas, as shown by equation a, the temperature will approximate to $2,600^{\circ}\text{C}$., at which even the best fire-bricks will melt, especially if at the same time they are in contact with basic substances.

In burning coal-gas with just the necessary air for complete combustion, injected into the burner by the aid of a steam-jet, the author, some years ago obtained a temperature in which the surfaces of the best ganister bricks melted like ice in the sun, which made it very clear that before even moderately high temperatures can be fully utilised, a very considerable amount of attention must be paid to the materials of which the furnaces will have to be constructed. There is ample room for some investigations upon the melting points of high temperature fire-bricks of definite composition.

It may be convenient here to introduce a table showing the heat developed by the combination of various elements with oxygen. Details of the sulphur combinations have also been introduced, as in some chemical operations the metallic sulphides are sources of heat, and the heat of combination of the sulphur with the metal will have to be deducted from the product obtained by oxidising the elements separately.

TABLE 5.

SHOWING THE HEAT OF COMBINATION OF VARIOUS ELEMENTS
WITH OXYGEN AND WITH SULPHUR.

Element.	Atomic weight.	C.H.U. per pound of element.	Substance formed.	Molecular weight.	C.H.U. per pound of substance.
Arsenic	75	1044	As ₂ O ₃	198	791
Calcium	40	3287	CaO	56	2348
"	40	2270	CaS	72	1261
Carbon	12	8080	Co ₂	44	2203
"	12	2473	CO	28	1059
"	12	—1583	CS ₂	76	—250
Copper	63.5	625	CuO	79.5	498
"	63.5	345	Cu ₂ O	143	306
"	63.5	157	CuS	95.5	104
Hydrogen	1	34462	H ₂ O	18	3829
Iron	56	1173	FeO	72	912
"	56	1746	Fe ₂ O ₃	160	1222
"	56	1612	Fe ₃ O ₄	232	1167
"	56	428	FeS	88	273
Lead	207	245	PbO	223	227
"	207	98	PbS	239	85
Magnesium	24	5975	MgO	40	3585
Mercury	200	107	HgO	216	99
Nickel	59	1042	NiO	75	820
"	59	330	NiS	91	214
Phosphorus	31	5890	P ₂ O ₅	142	2571
Potassium	39	1259	K ₂ O	94	1044
"	39	1327	K ₂ S	110	941
Silicon	28	6414	SiO ₂	60	2093
Sodium	23	2193	Na ₂ O	62	1627
"	23	1941	Na ₂ S	78	1144
Sulphur	32	2165	SO ₂	64	1082
"	32	3243	SO ₃	80	1297
Zinc	65	1304	ZnO	81	1047
"	65	661	ZnS	97	443

In the earliest days of water-gas the coke was placed in horizontal retorts wherein it was heated to redness, steam being admitted, but this method was soon found to be too costly and too uncertain.

In 1886 the water-gas producer came to the front in England, although it had been worked for years before in America, and in Germany, but for some reason it did not take hold here except in a few large gas-works. However, about this time, the owners of gas producers began to see the wisdom of introducing larger quantities of steam than usual into the air current supplying the producer, and thus the water-gas producer has acted as sponsor to the new regime.

The employment of larger volumes of steam in the producer was found to very considerably increase the yield of ammonia in the gaseous products

leaving the apparatus, and this discovery led to the complete reorganisation of plant for the production of gaseous fuel. In the gas industry, the production of ammonia equal to 28 lbs. to 30 lbs. of the sulphate per ton of coal is considered very good work, but in the modern gas producer 80 lbs. to 90 lbs. is the general amount collected from each ton of coal.

Figs. 5 and 6 show the details of the Duff producer, which is one of the most modern construction, and in which the uses of air and steam are properly combined. By the method employed in its construction, and from its design, the air and steam blast is evenly distributed over the whole area of the producer. The water seal shown in the illustration makes it impossible for any gas to escape, and as there are no clinkers when properly worked,

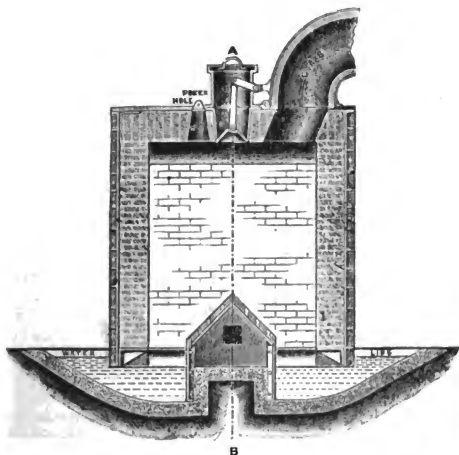


FIG 5 — DUFF'S GAS PRODUCER.

the ashes are easily removed from the base of the producer by unskilled labour. A section through the centre of this producer may be seen in Fig. 6, which shows the method of introducing the air by means of a steam jet, and the mode of distributing it equally over the whole surface of the producer.

Before proceeding further, a few remarks upon water-gas may be useful in enabling an accurate understanding of the subject to be arrived at. It has been already stated that when steam is passed through red-hot carbon a mixture of carbon monoxide and hydrogen is produced. Carbonic acid is, however, always present in quantities varying according to the maximum

temperature to which the steam is subjected when passing through the glowing layer of fuel. If the temperature be sufficiently high, then no carbonic acid is formed, but simply carbon monoxide and hydrogen; but when the temperature sinks, carbonic acid is formed, and, at the same time, proportionately less carbon monoxide. According to experiments made by Naumann and Pistor, carbonic acid, when passed over heated carbon, commences to be decomposed at about $550^{\circ}\text{C. (1,022^{\circ}\text{F.})$, at $950^{\circ}\text{C. (1,742^{\circ}\text{F.})}$ the transformation amounts to about 94 per cent., while at $1,000^{\circ}\text{C. (1,832^{\circ}\text{F.})}$ the decomposition is practically complete. The same reactions take place in the water-gas producer; at 500°C. the separation into hydrogen and carbonic acid is complete, while at $1,000^{\circ}\text{C.}$ or $1,200^{\circ}\text{C.}$ there is little other than carbon monoxide and hydrogen formed.

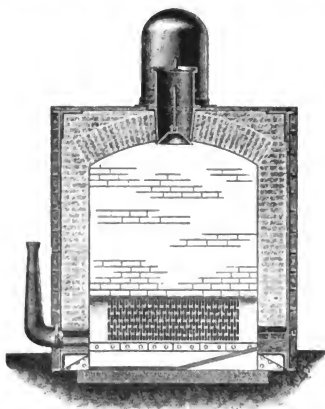


FIG 6.—DUFF'S GAS PRODUCER

We must imagine the process proceeding in such a manner as to suppose that there occurs, first, the transformation of the steam into hydrogen and carbonic acid, which, at a higher temperature, is reduced to carbon monoxide when it comes into contact with the glowing fuel.

One cubic metre of water gas contains half a cubic metre of carbon monoxide, and the same volume of hydrogen, or, to put it in another way, 0.27 kilo. of carbon and 0.403 kilo. of steam. This 0.403 kilo. of steam requires for its decomposition the same quantity of heat which has arisen at its formation, or 1,523 calories. During the decomposition of this 0.403 kilo. of water, the liberated oxygen, if we may

call it so, burns into carbon monoxide, by which means 648 calories are liberated, so that the addition of heat necessary in the generation of one cubic metre of water-gas amounts $1,523 - 648 = 875$ calories.

With reference to the heating power of water-gas, one cubic metre develops, in round numbers, 3,000 calories. The theoretical temperature of combustion (see Vol. I., page 269) amounts to $2,839^{\circ}\text{C.}$, as compared with that of carbon monoxide of $3,021^{\circ}\text{C.}$, and of hydrogen, $2,649^{\circ}\text{C.}$

Although these temperatures serve well enough to illustrate the subject, it is necessary to mention that the foregoing numbers are not strictly accurate, as they are based on the assumption that the specific heat of steam and carbonic acid are constant at these high degrees of temperature. This is, however, not correct, at least so far as regards steam, as, according to the

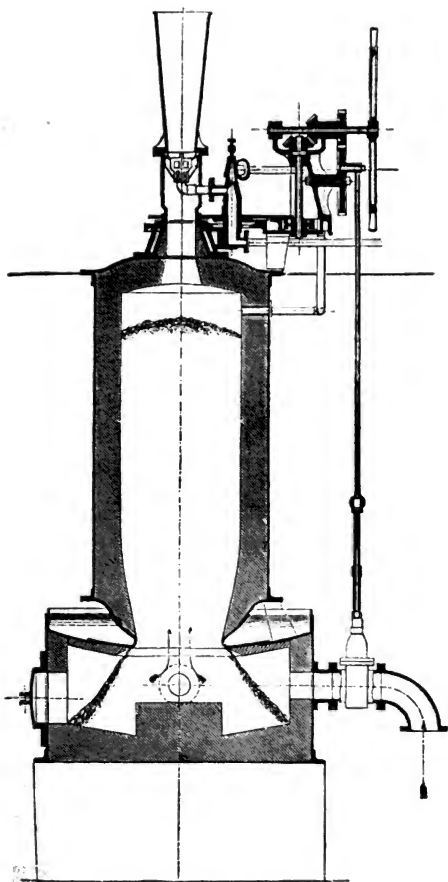


FIG. 7.—WATER-GAS PRODUCER.

experiments of Langen and Meyer, steam commences to dissociate at $1,200^{\circ}\text{C}$. but on the other hand carbonic acid is so permanent that it does not suffer any noticeable decomposition even at $1,700^{\circ}\text{C}$. Now as we must take into account in such calculations a greater specific heat, it follows that the temperatures calculated for the combustion of hydrogen must be too high, the error increasing with the temperature.

If we now consider the apparatus required for the carrying out of the reactions already cited, we shall find that they are usually performed in a generator or producer in which the fuel is alternately brought to a high temperature by means of a blast of air, and then a current of steam passed through the glowing carbon so that it shall be decomposed into hydrogen, the oxygen simultaneously forming carbon monoxide. During the warm blast, as the first operation is called, ordinary producer gas is being made, such as is made in the ordinary producer according to equation (b) (page 18), whilst during the passage of steam in the second operation, water-gas is being produced according to equation (c).

The sectional illustration shown by Fig. 7 will enable the reader to form a good idea of the construction of a small water-gas apparatus. In the larger sizes the head gear is much modified, but this illustration has been selected on account of its giving a clearer idea of the necessary operations than an illustration of the larger sizes would have done.

In this pattern the same opening in the head that serves for charging acts also for the chimney. In a plate, which by means of a hand-wheel is revolved round a fixed centre, there are three openings; in the first there is a chimney with a Körting steam-jet exhauster, in the second a charging hopper for filling in the fuel, and in the third a cover, closing the orifice. The fixed centre is constructed as a two-way cock or valve, so that on turning the plate steam enters either into the steam jet for suction or into the tube conduit for gas-making. When the charging hopper is over the opening, the steam is shut off altogether.

In making a substantially pure water-gas, the warm blast is kept on for a period of ten minutes, then the air current is stopped and steam admitted for five minutes, which constitutes the period for gas-making. In the apparatus shown by Fig. 7, the gas produced during the admission of air is lost, but there is clearly nothing in the way of utilising it for heating purposes, as it possesses a composition nearly equal to ordinary producer gas, according to the before mentioned equation (b) (page 18).

When the apparatus is constantly worked both night and day, 1,000 cubic feet of water-gas require about 198 lbs. of coke for its production, the coke being of the usual quality, containing about 20 per cent. of water and ash. If the apparatus is worked by day only, and closed down by night, then there must be added that quantity of coke that is burned uselessly during the night, which, however, should not be very great.

Water-gas gives a hotter flame than coal-gas, although its heating power in Centigrade heat units is so much less than coal gas (see Table 95, Vol. I.). The Fahnehjelm burner (Fig. 8), consisting of a number of magnesia rods, is easily heated to a white incandescence in the water-gas

flame, while in the ordinary Bunsen burner, fed with coal-gas, the light is practically *nil*. This is to be accounted for by a more rapid combustion, and in consequence of this a smaller flame surface is presented to the air, consequently there is less loss by radiation. An illuminating gas flame, consuming a similar quantity of coal-gas, presents at least six times the surface to the air as the corresponding water-gas flame, and so the temperature of the flame in the former case is considerably lower in consequence. A platinum wire will melt easily in the open water-gas flame showing a temperature of at least $1,700^{\circ}\text{C}$., while it is well known that a similar wire held in the ordinary Bunsen burner fed with coal gas is not melted except with great difficulty. It has been stated that the highest temperature noticed in the ordinary Bunsen is $1,350^{\circ}\text{C}$. When the generator gas produced is mixed with the water-gas also produced in the same apparatus, the mixed gas has approximately the same composition as the so-called "Wilson" or "Downson" gas, produced by blowing a mixture of air and steam into the producer, or the "Duff" gas already mentioned in this chapter, but the production



FIG. 8.—FAUREHJELMS BURNER.

of such a gas in this manner would be more costly than its manufacture in the "Duff" producer, and the apparatus is only mentioned here for the use of those who require a pure water-gas, or as a connecting link between the high temperature producer on the one hand and the low temperature producer on the other.

It has been already mentioned that during the transformation of carbon into carbon monoxide in the older forms of producer, 2,473 units of heat were disengaged, most of which was lost by the cooling of the gases from the iron main leading from the producer to the furnace.

In the most recent form of apparatus, this heat is utilised in, first of all, heating water to a high temperature, and with this hot water the air is moistened on its way to the producer.

When air is saturated at 0°C . with water vapour, the weight of moisture contained in a cubic foot of the mixture is very small. In fact, it amounts to no more than 0.0003 lb. (two grains), while at a temperature of 84°C . (the degree at about which the water is employed, as above described), the weight of moisture present in the mixture is 0.021 lb. (one hundred and forty-seven grains), or about seventy times as much as at 0°C . This is the principle underlying the construction and working of the Mond and Duff producer systems in which the gas is made, of which an analysis has been already given on page 326 of Vol. I. The Mond and Duff producers are both essentially low temperature producers, consequently the gas contains more carbonic acid than that made in any other form, but against this objection must be set off the fact that nearly the whole of the nitrogen of the slack

is converted into ammonia, which in a complete modern producer plant is ultimately recovered as sulphate of ammonia. Moreover, the heat liberated by the combustion of the carbon to carbon monoxide is to a great extent utilised, as it produces the water vapour which is driven into the producer.

Where no attempt is made to recover the ammonia (and this is not profitable with a fuel consumption of less than forty tons per week), these producer systems show no advantage over the "Dowson" producer, but in large installations the recovery of 90 lbs. of sulphate of ammonia per ton of slack is an item of great importance. The gas from a heavily steamed producer must be considered as ordinary Siemens-producer gas, with an admixture of water-gas, but instead of working in alternation as already described under the head of water-gas, the two operations run concurrently, and there is an equable temperature in the producer.

The effect of steaming the red hot column of coke in the water-gas producer may be seen from the following figures, which show the percentage composition of the gases after one, two and a half, and four minutes of steaming:—

	1 m.		2½ m.		4 m.
Carbonic acid	1·8	..	3·0	..	5·6
Carbon monoxide	45·2	..	44·6	..	40·9
Methane	1·1	..	0·4	..	0·2
Hydrogen	44·8	..	48·9	..	51·4
Nitrogen	7·1	..	3·1	..	1·9
	<u>100·0</u>		<u>100·0</u>		<u>100·0</u>

The effect of the reduction of temperature upon the percentage of carbonic acid is seen most clearly in the foregoing figures, and in the next set, which sets out the composition of the warm blast gases after one, six, and ten minutes' injection of air, shows how well the carbonic acid is converted into carbon monoxide so soon as the temperature has been restored.

	1 m.		6 m.		10 m.
Carbonic acid	7·04	..	4·03	..	1·60
Carbon monoxide ..	23·68	..	28·44	..	32·21
Methane	0·44	..	0·39	..	0·18
Hydrogen	2·95	..	2·20	..	2·11
Nitrogen	65·80	..	64·94	..	63·90
	<u>100·00</u>		<u>100·00</u>		<u>100·00</u>

One kilo. of coke, containing 84·8 per cent. of carbon, yields 1·13 cubic metres of water-gas, containing 0·291 kilo. of carbon, and 3·13 cubic metres of producer gas, containing 0·557 kilo. of carbon. The water gas and the producer gas have each a heating power expressed by the same number of thermal units. When steam is employed in the producer, the weight of fuel gasified per hour is greatly in excess of that when a natural draught only is employed. In some experiments, the details of which have been already published (1893), a Siemens producer with natural draught gasified 2 cwts. per hour, while, when it was steam-blown, it turned into gas no less than

4 cwts. of fuel per hour, thus doubling the capacity of the apparatus. The same effect is also observed when the draught is created by mechanical means, such as the Roots blower, or the Sturtevant fan.

What is known as the Dellwik-Fleischer gas producer is an apparatus in which the reaction (b) (page 18) is to a great extent suppressed, the object being to intensify as far as possible the reaction (c). As the chemical reactions in the generation of water gas are always the same it has been found possible to establish conditions in the generator so that during the blows a practically



FIG. 9.—THE DELLWIK-FLEISCHER GAS PRODUCER.

complete combustion to carbon dioxide is obtained within the bed of coke to be heated, while at the same time conditions favourable to water gas making are maintained. This is a radical difference between the old water gas apparatus and the new, and it is a most important difference, as it enables a much larger proportion of gas to be made from the unit weight of coke. The process was well described by Mr. Carl Dellwik in a paper read before the Iron and Steel Institute in 1900, from which the following particulars have been taken :—

Fig. 9 will enable the reader to get a good general idea of the disposition of the apparatus, of which the generator is the most important part. The sheet-iron shell is lined with firebrick. On a level with the clinkering doors is a grate supporting the fuel; below are ash doors for removal of the ashes. The air enters through the blast valve, and the blow gas leaves the generator through the central stack valve, through which the fuel is also charged by means of a small coke wagon. There is one water gas outlet at the top of the generator, and one below the grate, both connected with a three-way valve, through which the gas passes on its way to the scrubber. The gas pipe is sealed with water in the bottom of the scrubber, where the gas is cooled and all dust washed out by the water running through the coke, with which the scrubber is filled. From the scrubber the gas passes on to a small holder, which equalises the flow of gas to the place of consumption. There is a steam pipe leading in to the bottom and one to the top of the generator.

The method of working the generators illustrates the difference from the old methods. In the latter the duration of the blow was from 10 to 15 minutes, while the water gas was made during the following 4 or 5 minutes. In the Dellwik generators the blow lasts only $1\frac{1}{2}$ to 2 minutes, while water gas is subsequently generated for 8 to 12 minutes. During the blow the combustion continues throughout the entire depth of the fuel, and the whole bed of fuel is thus raised to an even high temperature, enabling the periods of water gas production to be considerably lengthened without any deteriorating effect on the quality of the water gas.

When 1 lb. of carbon is burnt to carbon dioxide (CO_2), it develops 8,080 heat units ($^\circ\text{C}$); when burnt to carbon monoxide (CO), it gives off only 2,473 heat units. As the Siemens process consists in burning the carbon to carbon monoxide, it follows that the gas produced from 1 lb. of carbon contains $8,080 - 2,473 = 5,607$ heat units ($^\circ\text{C}$), corresponding to a utilisation of about 70% of the heating value of the solid carbon. This figure, therefore, roughly represents the maximum theoretically possible utilisation in the cooled gas of the heating value of the fuel, when losses from radiation and other sources are not taken into account.

In the old water gas processes the producer gas formed during the "blows" is amply sufficient for generating the steam needed for the process, though, as before mentioned, it has by no means always been so used. When a combustion to carbon dioxide is effected in the generator, this advantage is, of course, lost, the waste heat being only sufficient for pre-heating the feed water for the boiler. It is, therefore, necessary in this case to add for boiler fuel 12 to 15 per cent. to the fuel used in the generator. This reduces the theoretical quantity of gas obtainable from 12 lbs. of carbon to 656 cubic feet, and the possible utilisation of the heating value of the fuel to about 80 per cent.

The most trustworthy figures for continued work have been obtained from an installation at the Corporation Gas Works at Königsberg, in Prussia, where an average yield of 38.44 to 39.62 cubic feet of water gas are obtained per pound of carbon contained in the coke which is charged into the gene-

rator. This corresponds to a utilisation of 75·2 to 77·7 per cent. of the calorific value of the fuel. At another gas plant the tests showed a yield of 41·6 cubic feet per pound of carbon, or an efficiency of 81·3 per cent.

The method of working is as follows :—A fire having been built on the grate, and the generator filled to the proper level with coke, the blast valve is opened, and the fuel raised to a high degree of incandescence in a few minutes. Then one of the gas outlets—the upper one, for instance—is opened, the blast and stack valves being simultaneously closed by means of the gearing on the working stage. Steam is then admitted to the bottom of the generator, and, passing up through the bed of incandescent coke, is decomposed, forming water gas. A set of water gauges and a test flame indicate the condition of the apparatus and the quality of the gas. When the temperature of the fuel has sunk below the suitable point, so that carbon dioxide begins to form in a larger proportion, the steam is shut off and the stack valve opened, the gas valve being simultaneously closed. The blast valve is then opened for another blow of one and a half to two minutes. For the next period of gas-making, the lower gas outlet is opened and steam admitted above the fuel. By thus reversing the direction of the gas-making the temperature of the fuel is equalised, causing less wear on the brick lining at any one point. The greater part of the coke being consumed by the action of the steam, the incombustible portions of the coke to a large extent disintegrate and fall through the grate as ash, while the clinkers on the grate are brittle and easily removed.

The heating value of water-gas, although only half that of coal gas, or one third that of natural gas, is, however, from two to three times that of Dowson, Mond, or Siemens gas, and consequently can be used to great advantage for many technical purposes. It is employed for welding iron, melting glass, bronze, and bullion, and for burning magnesite and cement. It is used also in the chemical industries for cyanide furnaces, in the manufacture of soda, aniline colours, starch, sugar, etc., and for the heating of platinum stills. It is possible by means of water gas to melt platinum, the melting point of which is 1,780° C., and by previously heating both gas and air to a high temperature, a magnesite furnace may be heated to 1,900° C.

What are known as suction producers, of which there are not many types, need not be described here. A description of one of them may be found on page 329, Vol. I., which will give the reader some general information as to their construction and uses. There is still ample room for invention which must take the form of substituting coal for coke in this type of producer.

The appliances necessary for securing the thorough combustion of producer gas are not elaborate. A ton of slack, gasified in the low temperature producer, will make 160,000 cubic feet of gas, if the slack contains 85 per cent. of carbon. A ton of slack burning to gases containing 16 per cent. of carbonic acid (see Table 89, Vol. I., page 270), will require about 166 cubic feet of air per pound, or 371,840 cubic feet in all, producing

approximately a similar volume of waste gases, so that we require :—

Producer gas	160,000	cubic feet
Air	211,840	" "
Products of combustion	371,840	" "

This will show us that, under similar temperatures and pressures, the gas main and the air conduit should have areas in equal proportion, the air being usually introduced at the normal atmospheric temperature, while the gas is often at 150° C. If both gas and air be admitted at the same temperature, the areas should be in the proportion of 16 to 21 respectively. The actual combustion of the gas, and the appliances necessary to distribute the heat, must, of course, depend upon the style of furnace and nature of the

operations to be carried on, but it is seldom necessary, in the case of producer gas, to do more than to build the gas flue and air conduit parallel to each other, as shown in Fig. 10, and so arrange matters that both air and gas shall be under complete control, so far as quantity is concerned, by means of suitable valves. This is much better shown in Fig. 11, which was an arrangement adopted some years ago to heat a Porion evaporator. The gas and air entrances may be readily followed, as well as the disposition of the valves employed to control the flow of the same.

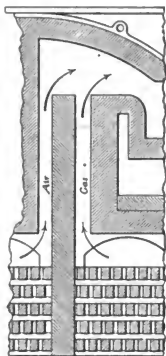


FIG. 10.—
AIR AND GAS FLUES.

When the proportion of air needed for combustion is greater than that in the foregoing instance, as with natural gas, coal gas, or water gas, the principle of the Bunsen burner should be adopted. In the case already mentioned on page 11, the coal gas was burned under the tar still in a giant Bunsen, six inches in diameter and five feet long. The nozzle bringing the gas within the Bunsen was bored to a diameter of five-eighths of an inch, which was found more than sufficient for a twenty-ton tar still. Great attention must be paid to the method of introducing the air in such burners, especially when they are connected up with powerful chimneys. The pull of the chimney is apt to draw in much larger volumes of air than originally intended, with the result of causing the flame to strike back to the gas nozzle, in which case the Bunsen tube will soon be burned away.

A nozzle, bored to the same diameter as the foregoing, will serve for the flue of a steam boiler of Lancashire type thirty feet in length, while a nozzle bored to half-an-inch and three inches long, will pass sufficient coal gas, under a pressure of $2\frac{1}{2}$ inches of water, to keep an oven holding six or seven gas retorts to the maximum degree of heat needed for gas

making. The illustration, Fig. 12, on next page, is a drawing of the half-inch burner to scale.

Liquid fuel has been already mentioned, but the appliances for burning it have not yet been noticed. There are many forms of liquid fuel burners in the market, but there is no need to mention more than one. The operation is a simple one, but needs care in one or two directions. In the first place, the oil or tar must be clean and free from dirt, as the nozzle through which it is fed is bored with so small an orifice that it soon becomes clogged if any dirt or solid matter reaches that point. In the second place, the

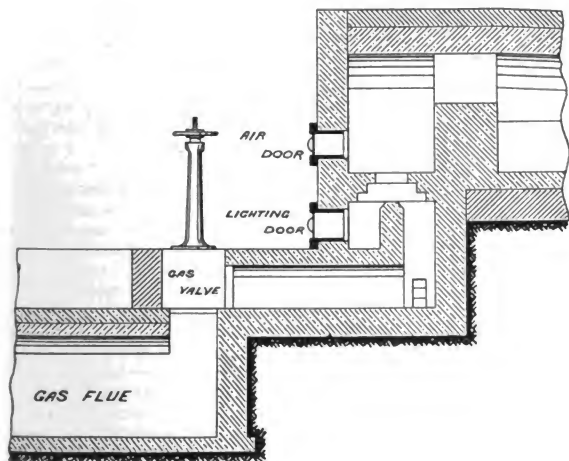


FIG 11.—GAS-HEATED PORION EVAPORATOR.
(Showing arrangement of air and gas flues.)

supplies of steam and tar must be proportionate, and the areas of the nozzles carefully calculated out; an excess of steam cools down the furnace, and an excess of air does likewise, so that the regulation of both these agents should be under perfect control.

There is one characteristic of the liquid fuel burner that must not be overlooked, and that is its short and intense flame. In all well-constructed steam jet atomisers made for this purpose, this local intensity of the flame must exist, and can only be modified at the expense of efficiency. Carefulness must therefore be exercised in directing the flame against some undamageable portion of the apparatus, such as a wall of loosely

built fire-bricks, or fire-brick slabs placed on the bed of a fire-place. The entrance of useless air must be particularly guarded against, as with these burners no chimney draught is requisite, and so long as the waste products of combustion are carried above the heads of the attendants there is no further need for a chimney.

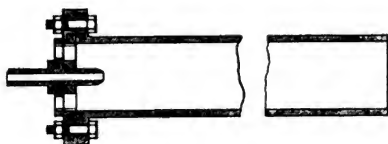


FIG. 12.—GIANT BUNSEN BURNER.

The liquid fuel burner of Messrs. Körting, shown in Fig. 14, is an appliance that will do its work satisfactorily, and the method of its action may be now explained.

The apparatus is strongly constructed of cast-iron, and consists in

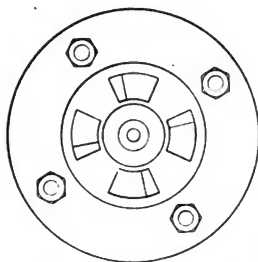


FIG. 13.—GIANT BUNSEN BURNER.
(Arrangement for Air Regulation.)

the main of a pipe through which the liquid fuel, coming from an overhead tank, runs in a thin stream. This portion of the apparatus (letters *E* to *H* in the illustration), consists of a filter at *S*, and a removable nozzle at *A*, the details of which must be carefully attended to. When the liquid fuel falls into the lower part of the apparatus, it meets with a jet of steam placed at a suitable angle, and becomes "atomised," or riven into very small particles, which become mixed with the air which is also projected into the furnace by the steam jet. Any apparatus installed for the burning of liquid fuel should be capable of being easily cleansed without taking

the appliance to pieces, and this is a special characteristic of the Körting burner. The nozzle can be cleaned by lifting up the sliding tube *H*, and in this way both upper and lower pipes may be unscrewed without disturbing the parts *E* or *Z*. The spray apparatus itself can be cleaned while working without any danger, by taking out the plug *I'* and pushing the needle *R* through the orifice.

As already mentioned, attention must be paid to the proper regulation of the air supply, and to see that the flame does not impinge upon the surface of boiler plates, for if it does it will most assuredly blister them. Regulate the supply of air so that the flame is *almost* smokeless

and leave the combustion chamber to do the rest. Work with the damper as nearly closed as possible—chimney draught is only required to take away the products of combustion, and as the steam jet takes in the necessary quantity of air for combustion, any excess drawn in by the chimney is so much waste and loss of efficiency. Furnaces have been designed for burning liquid fuel, in a trough or gutter, without the aid of a steam jet, and they have been at times employed by the author, but, after a lengthy use, the conclusion was arrived at that those who preferred them could not possibly have been acquainted with the simplicities of the steam jet system. The method whereby the oil is converted into gas before combustion is too complicated and costly to be practically considered; moreover, such complications are entirely unnecessary.

The combustion of liquid fuel by the aid of a steam jet serves to bring us into contact with the system of forced draught. It is not an uncommon thing now-a-days to see furnaces or steam boilers fitted with mechanical draught apparatus, and, as we know that a good draught can be produced and maintained without such appliances, it behoves us to investigate the matter so as to set out under what conditions the one may be more economical than the other.

Of course, it is well known that a very small difference in temperature between the gases inside a chimney and the air outside will produce a considerable draught. We shall see presently, when chimneys come to be considered, that sufficient draught for the combustion of the normal quantity of fuel can be secured with a temperature less than the boiling point of water, and it is common knowledge that gases at this temperature are not otherwise useful as an economical source of heat. Now if these gases, which are of but little use for any other purpose, are sufficient to produce the draught, how can it be profitable to separately generate

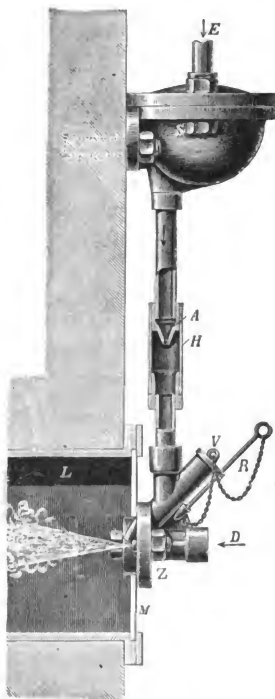


FIG. 14 — LIQUID FUEL BURNER.

mechanical power for its production? There may be instances—and a careful perusal of the remarks that follow will enable them to be isolated.

On pages 442 and 454 of Vol. I. some particulars were given of colliery ventilation by means of the furnace system, to which the reader is again referred. It was pointed out that only one-half of the added heat in the gases leaving the upcast shaft, in this instance, could possibly have emanated from the coal burned in the furnace, and that the actual work done was 38 H.P. from which data a balance sheet may readily be prepared as follows :—

FURNACE AT FOOT OF UPCAST.
(Per Minute.)

Received.	Foot Pounds.	Expended.	Foot Pounds.
Foot pounds from the combustion of 8 lbs. coal	80,000,000	Raising 94,960 c. ft. of air 170 ft. high = 38 H.P.	1,254,000
Foot pounds due to the passage of air through workings	80,000,000	Heat lost in escaping air in conduction, etc.	158,746,000
	160,000,000		160,000,000

$$\text{Theoretical efficiency } E = \frac{1,254,000}{160,000,000} = .784\%.$$

We may now examine the efficiency of draught when produced from coal through the medium of a steam-engine and fan, when we shall find that the economy of the operation, or otherwise, will depend upon the efficiency of these mechanical adjuncts. Theoretically, a very good case may be made out for the introduction of mechanical draught, especially if the waste gases from the furnaces can be thoroughly utilised, but if this cannot be effected, it is more than probable that in most cases mechanical draught will prove an expensive luxury.

In arguing this question, it has been usual to assume that the gases escape from steam boilers at 300° C. This may be so when no special effort is made to economise the heat in the waste gases, but it is not fair argument to compare a neglected installation on the one hand and more perfect one on the other in order to prove a principle. If a set of steam boilers be fitted with a superheater next to the boiler itself, followed by a water-heating economiser, and that again connected with an air-heater of the tubular type, the temperature of the gases will be so reduced that they will barely measure 150° C. when they reach the chimney. Twenty pounds weight of gases per pound of fuel passing away at a temperature of 150° C. means 720 Centigrade heat units, which is a 90 per cent. utilization of the fuel. As to the effect of such reduction of temperature

upon the draught, that will be referred to later on, but that no fears may be entertained on this account, the reader may turn to Table 6, which furnishes much food for reflection.

If we refer again to Table 98, on page 346 of Vol. I., we shall find that the amount of fuel consumed per I.H.P. by the power plants examined by the Manchester Steam Users' Association, averaged 7 lbs. per horse-power hour. Let us take this figure and see how it works out with a fan of 20% efficiency to move the 94,960 cubic feet of air per minute through a height of 170 feet, as in the former case, the work to be done being 38 H.P., so that 20% efficiency means the actual supply of 190 H.P.

FAN AND STEAM ENGINE.

(Burning 7 lbs. fuel per H.P. hour.)

Received.	Foot Pounds.	Expended.	Foot Pounds.
Foot pounds in coal necessary to drive fan, supposing engine to burn 7 lbs. coal per H.P. hour, fan 20 per cent. efficiency, 22 lbs. coal	220,000,000	Raising 94,960 c. ft. air 170 ft. high, or 38 H.P.	1,254,000
		Loss in fan of 20 per cent. efficiency ..	5,016,000
		Other losses	213,730,000
	220,000,000		220,000,000

$$\text{Net efficiency } E = \frac{1,254,000}{220,000,000} = .57\%.$$

The foregoing figures show us clearly, that under ordinary circumstances when employing an engine using the steam produced from seven pounds of coal per horse-power hour, with a fan showing but 20 per cent. efficiency, it is more costly to employ forced draught than to generate it by the combustion of coal, and this being the case, how much more costly must such mechanical draught be when it is made to replace that which is generated by the heat escaping from fuel after it has given up all that can practically be squeezed out of it. The yield of air from fans, and the power taken to drive them, are points that still require considerable attention.

This is not the case, however, with the ventilation of collieries, where the engines are of modern type, compounded and condensing, and in which $2\frac{1}{2}$ lbs. or 3 lbs. of coal yield the product of one horse-power hour. Moreover, the larger the fan, *cæteris paribus*, the greater its efficiency, and if we reckon upon a yield of 50 per cent. combined with the previous fuel economy, we shall find an enormous saving in the use of mechanical draught. Let us now look at a balance sheet in which the foregoing figures have been used.

FAN AND STEAM ENGINE.

(Coal 3 lbs. per H.P. hour. Fan efficiency 50%.)

Received.	Foot Pounds.	Expended.	Foot Pounds.
Foot pounds in coal necessary to drive fan, supposing engine to burn 3 lbs. coal per H.P. hour, fan 50 per cent. efficiency, 3.8 lbs. coal	38,000,000	Raising 94,960 c. ft. air 170 ft. high, or 38 H.P.	1,254,000
		Loss in fan at 50 per cent. efficiency	1,254,000
		Other losses	35,492,000
	38,000,000		38,000,000

$$\text{Nett efficiency } E = \frac{1,254,000}{38,000,000} = 3.3\%$$

Thus it is clearly shown that in small installations driven by ordinary non-condensing steam engines mechanical draught may become an expensive luxury, and especially so when a steam engine is employed to drive a dynamo, the dynamo to drive a motor, and the motor the fan, as very considerable losses take place at each stage of the process.

Again, it is a well known fact that the steam jet blower is not so economical an appliance as the fan or rotary blower, but there are circumstances in connection with the use of the steam jet blower that deserve careful consideration. Excessive heat in the region of the fire-bars is a condition to be avoided as far as possible, as at a high temperature, the clinker fuses and adheres to the bars, causing no end of trouble and expense. Now, on referring to the formula *c* on page 18, it is shown there that steam blowing upon red-hot carbon is decomposed, forming carbon monoxide and hydrogen. This reaction takes place as surely in the region of the fire-bars of a steam boiler furnace when a steam-jet blower is employed to create the draught as it does in the interior of a gas producer, with the result that the fire-bars are kept cool and prevented from burning out, and the clinkers do not flux as in an ordinary fire. The heat absorbed during the decomposition of the steam is not, however, lost, it is only transferred from the region of the bars where its presence is noxious to the topmost layer of the fuel, where its presence is beneficial.

There are but few figures available for estimating the efficiency of the steam-jet blower, but Peclet gives us some figures that may be found of interest, and we may get some information from the "souffleurs" of the Kessler concentrating apparatus. In M. Méhu's experiments cited by Peclet, using steam of five atmospheres in a tube 8 ins. diameter and 40 ins. in length, through a jet $\frac{1}{4}$ in. bore, the quantity of air passed through the tube amounted to over 200,000 cubic feet per hour. The work done

amounted to 0.355 H.P., while the steam actually used was equal to 6.4 H.P. In this connection it may be mentioned that Peclet cites the case of a brewery in Louvain in which a fan consuming 6 H.P. served to produce draught for nearly one ton of coal burned per hour. If we allow 250 cubic feet of air per lb. of coal this means a supply of 560,000 cubic feet per hour, which, at 8 lbs. of coal per horse-power hour, gives the work of the fan as 11,666 cubic feet per pound of fuel. Some authentic figures for mechanical draught are still wanting. Turning to the Kessler evaporator, the figures given by Kessler himself show that 220 lbs. of coke are required per ton of concentrated acid for heating and evaporating the acid, and 176 lbs. for steam to work the "souffleur" or steam-jet exhausting arrangement. As the coke is burned in a generator or producer for the evaporation proper, and the steam furnished from the steam-generating plant, it follows that the 176 lbs. of coke are used for exhausting the gases produced from the 220 lbs. burned in the producer. If we allow 300 cubic feet of gases per pound of coke burned in the producer, we shall have practically 375 cubic feet exhausted per pound of coke, which is certainly a very poor performance when compared with the former figures.

But there are some conditions under which forced draught, whether produced mechanically or by steam jet, possesses certain advantages. It may be that the capacity of the steam-raising plant has been exhausted with natural draught and ordinary hand firing. If there does not happen to be room for the provision of extra boilers, forced draught will help to burn as much as 30 lbs. or even 40 lbs. of fuel per square foot of grate surface per hour, and this may be effected with no more smoke from the chimney than is usual when 20 lbs. of fuel are burned with natural draught.

Undergrate blowers have been in use for many years. At first they were not so well designed or understood by the users as they are to-day, and the author well remembers the banter upon the installation of one of them in 1875 at the works of the St. Helens Chemical Company, when it was said that the blower consumed all the steam raised in creating draught enough to burn the fuel. To-day this is by no means the case, as the steam used in creating the draught is not missed, the small quantity used in this way being quite overshadowed by superior efficiency.

Körting's was the first practical undergrate blower, and next came Meldrum's, and these two systems of steam-jet appliances have yet no superiors, though many modifications of their systems have been patented and repatented. The Meldrum forced draught system consists in simply closing the ashpit and injecting the necessary air by means of a steam jet blower, the bars, which are of special pattern, being placed closer together than the bars of ordinary steam boilers working with natural draught. The steam entering with the air keeps the bars comparatively cool, and there is no difficulty in removing the clinker. The fuel is well burned, no combustible matter being left in the ashes. This is a very important point, as, with natural draught, the amount of carbon left in the ashes is sometimes very great. In a case known to the author, the ashes from a long range of steam boilers were carted on to a canal towing path, with

which to make the road, at the rate of 20 tons per week. After this had been going on for two years, these ashes were sampled and found to contain 27 per cent. of carbon. Captain Cuttle's advice may be taken here.

What has just been said of the Meldrum forced draught system is sufficiently descriptive of the method generally adopted, so that it only remains to say a few words as to the carrying out of the system in practice, and the remarks which follow may be applied equally to all varieties of forced draught furnaces.

Theoretically, but little draught by the chimney should be needed, as all that would seem necessary would be to take away the products of combustion as fast as they are formed. It has been already pointed out, when dealing with liquid fuel burners, that the flame must not impinge on the iron plates of the boiler, as in such a case their destruction will follow as a matter of course. With a sluggish draught at the chimney end, the flame from an undergrate blower will impinge upon the top plates of a boiler flue in most of the patterns, and, if this occurs, the plates will suffer. If, however, there is a keen draught at the chimney end, it will pull the flame from its vertical direction, so that it does not impinge directly upon the plates, and, in this case, they will not suffer from the intense heat.

Marine boilers seem in the past to have suffered more from forced draught than land boilers, though it is not certain how this comes about. Probably the increased furnace temperature has something to do with it, combined with the strains to which all marine boilers must be subject. At the same time land boilers have suffered from forced draught, but chiefly in the direction of blistering the plates. In working with natural draught, the carbonic acid in the waste gases of combustion seldom exceeds 10 per cent. by volume, while with forced draught the percentage of this gas often rises to 15 per cent., and even more. If we refer to Table 89, Vol. I., page 270, we shall find that the theoretical initial temperature of combustion with 10 per cent. of carbonic acid would be $1,550^{\circ}\text{C.}$, while with 15 per cent. of carbonic acid the theoretical temperature is calculated at $2,237^{\circ}\text{C.}$ Of course these are not actual temperatures, but there is much upon which to base the assumption that the higher temperature obtained with a lessened air supply will be more destructive to boiler plates if a flame at that temperature is allowed to impinge upon them, than if the flame were at a lower temperature, and struck the plate at an angle, owing to the action of a stronger draught. The actual fuel burned per square foot per hour seems to have but little to do with the question, as from 50 lbs. to 80 lbs. per square foot per hour is quite common in locomotive furnaces, which do not suffer unduly, while 50 lbs. is quite an average rate of combustion in marine boilers, and also for land boilers worked with forced draught. Increasing the pressure of the draught above a very low limit does not seem to exercise any beneficial influence, if we may place reliance upon the figures which have been published. In some figures obtained with Thorneycroft's* water-tube boiler, using natural

* Proc. Inst. C. E. Vol. 99.

draught, the apparent total absorption of heat varied from 80 to 89 per cent.; with forced draught under one quarter of an inch water pressure, the amount absorbed was 85 per cent.; under half an inch pressure, 82 per cent.; and with two inches of water pressure, the total apparent absorption was only 77 per cent.

Some of the undergrate blowers in use are so constructed that the furnaces to which they are attached are not provided with bars of the usual type. Many coke-breeze furnaces are of this pattern, and of a like kind is Mr. Peter Norman's slack or dross furnace. In the latter form of forced draught furnace the air chest A.A. is covered with bent plates (marked c.c. on the accompanying illustration, Fig. 15), upon which the fuel is placed, the clinkers being removed from the furnace front by means of a door specially provided for the purpose.

It will be seen that the principle upon which all furnaces of this description are constructed admits of almost unlimited variation in detail, no doubt to the great delight of the Patent Office, but to the confusion of all those to whom such apparatus is exhibited.

Some years ago Messrs. Bryan Donkin and Clench, Ltd., introduced the Perret furnace, chiefly in gas-works, with the object of utilising the small coke or "breeze," then a drug in those establishments, and it has also been successfully applied to the burning of small slack and "dross." In this furnace the draught is produced by mechanical means, the following illustration (Fig. 16) showing such details as will enable the reader to follow the description.

A cast-iron trough runs the whole length of the furnace, and this is kept filled with water by means of a small cistern and ball-tap. The fire bars are provided with deep gills or fins, which dip into the water in the trough, and so the clinkers are prevented from sticking to them. The air blast is supplied by a fan, the air entering a closed ashpit, as shown in the illustration, being regulated by a throttle valve immediately in advance of the boiler front. In actual practice, it is found that ordinary gas-coke breeze will evaporate 5 lbs. of water per lb. of breeze, and coal dust about 7 lbs., varying, of course, with the quality of the fuel as to moisture and ash contents.

We may now turn our attention to mechanical stoking, which is illustrated by the automatic mechanical stoker of Messrs. T. and T. Vicars, of Earlestown, shown in section by Fig. 17.

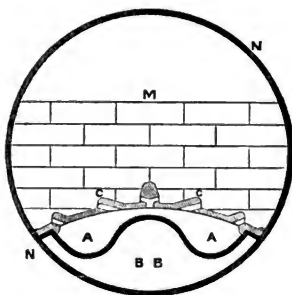


FIG. 15.—
NORMAN'S PLUS PRESSURE FIREPLACE.

In this form of stoker the fuel is fed from a hopper into two cases or boxes, from which it is gradually pushed by reciprocating plungers, alternately, into the fireplace, where it falls on to the fire bars at the front end. These bars, by a slow reciprocating movement, carry the burning mass gradually backward. The clinkers and ash refuse, which are carried back to the end of the bars, are discharged over the ends into the flues, wherein they form up and maintain a bank, which acts as a bridge, closing the far end of the ashpit, and on which the combustion of the fuel is completed. An ordinary fire-brick bridge is built in the furnace flue, about four feet from the ends of the fire bars. The supply of fuel, and the travel

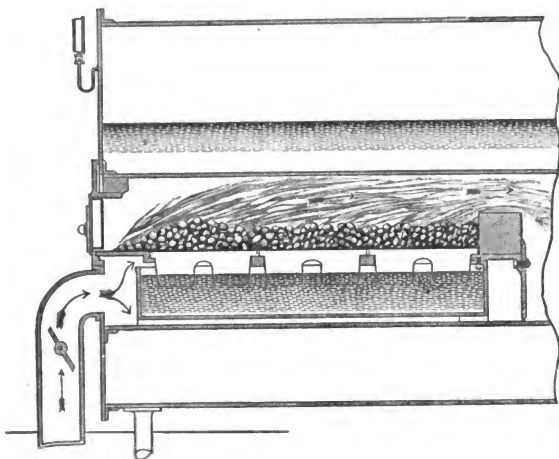


FIG. 16.—BRYAN DONKIN & CLENCH'S PERRET FURNACE.

of the fire bars, are each capable of easy regulation. The alternate fire bars are lowered and drawn towards the front of the furnace, and then all the bars travel inward together, the motion being derived from a driving shaft, on each end of which an eccentric is fixed. By means of cams on this shaft the horizontal movements of the fire bars are effected, and the speed of this motion can be regulated to the extent of four times their slowest velocity, that is to say, from 30 to 120 turns of the shaft per hour. The illustration shows clearly enough how these various motions are effected, and it may be seen how all the complicated forms of mechanical stokers have, in their development, been shorn of their complications. The travelling bar has, however, not been civilised out of existence. It appears

to be a necessity. As to the value of this stoker, testimony may be found in "A Text Book on Steam and Steam Engines," by Prof. Andrew Jamieson, who writes: "An excellent example of this mechanical stoker is now working on the boilers supplying steam to the engines driving the high-

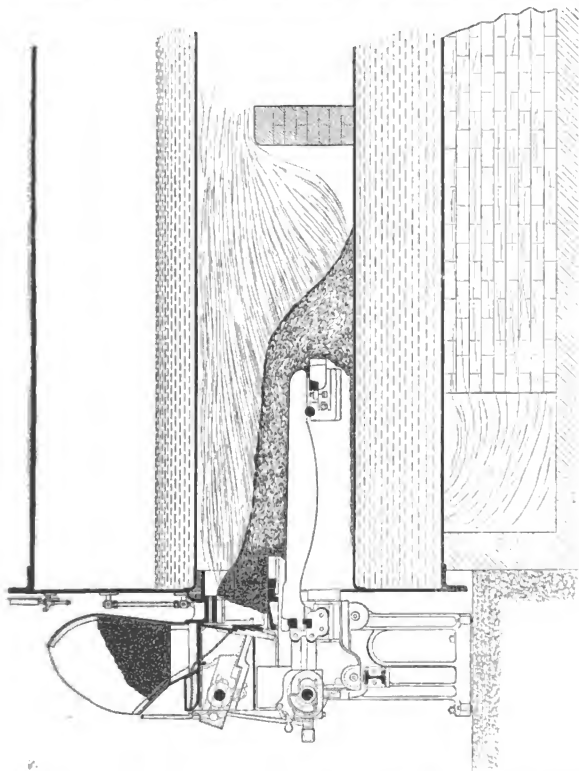


FIG. 17.—THE VICARS MECHANICAL STOKER.

pressure air-pumps for the contractors of the Central underground railway in Glasgow. Although the boilers are supplied with ordinary nuts from local coal pits, not a particle of smoke can be seen issuing from the chimney situated in Enoch Square. The whole secret of this thorough smoke con-

sumption lies in the fact that the gases as they arise from the crude coal are raised to that degree of temperature, and are supplied with that necessary quantity of air, which will just induce them to become inflammable."

In Bennis's machine stoker the fuel falls from a hopper into a feeding box, in which there is a very simple pusher plate. A certain quantity of fuel falls in front of this plate, and is pushed over a ledge formed by the bottom of the box. The fuel thus pushed over falls on to a flat plate, which is called the "shovel box," from which it is projected into the fire by a shovel, which, striking the fuel, propels it forward and scatters it in a most effectual manner, without shock, jar, or noise.

The compressed air furnace used with this stoker consists of tubular fire bars, which all move into the fire together for a distance of about two inches, and are then drawn out one by one, by the action of the cams placed upon the shaft. The cams are made the full width of the bar, so that the tear and wear is very small. By the action of the bars, the ash and clinker are slowly carried to the back end of the furnace, where they drop into a closed chamber, from which they are periodically removed. The bars are constructed with exceedingly narrow air spaces, so that coke-breeze or dust fuel may be burned with advantage.

The Meldrum "Koker" stoker shown in Fig. 18 is another form of the compressed air mechanical stoker, in which the automatic regulation of the feed, the operation of the fire bars, and the combined high and low pressure forced draught, form distinctive features. The fuel is stored in the usual hopper, at the bottom of which is a cylindrical casing, in which the fuel ram oscillates. The ram, which is an entirely new departure, consists of a sector working on a pivot instead of being flat and sliding backwards and forwards. By this means much less power is absorbed in working it, and as the speed with which it works is variable, being capable of regulation at will without stopping the machine, the improvement is worth recording.

The fire bars of this furnace are waved upon the face, so that when placed in position in the furnace they present an undulating surface. The bars are operated by cams, which, acting against the lugs on the former, first push all the bars towards the back of the furnace, whereby the bed of fuel is moved forward, and, as the cams rotate, they bring back the bars in sections. The action thus introduced detaches the fuel and prevents clinkering, as in the two previous forms mentioned. For the complete combustion of the fuel, a blast of superheated air at high pressure is introduced into the back of the hopper in order to coke the fuel, while the rest of the air supply enters the furnace through side grids in the shield plates. This furnace is practically smokeless, even when burning from 35 to 40 lbs. of fuel per square foot of grate surface per hour, and the air supply, both above and below the grate, is so completely under control, that but a small volume of excess air is needed to bring about complete combustion.

The "Sprinkler" stoker made by the same firm is shown attached to a Lancashire boiler in Fig. 19. This form of mechanical stoker has moving bars to deliver the clinker to the clinker pit in most installations,

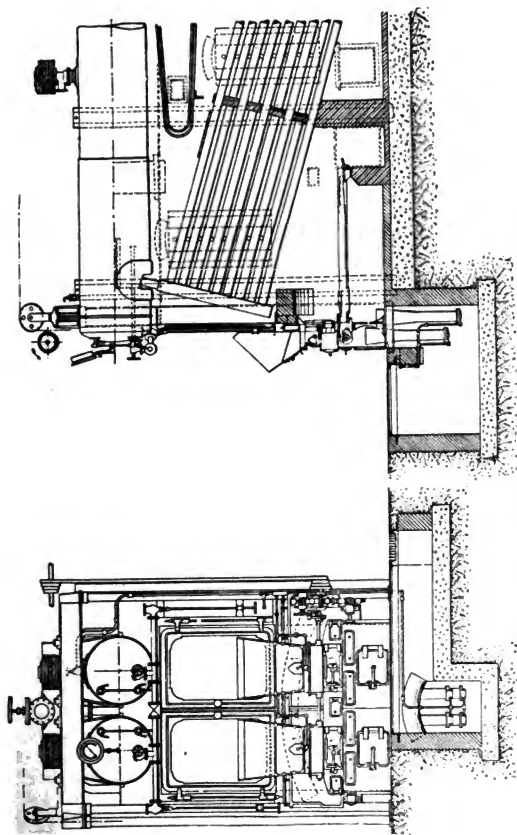


FIG. 18.—BARCOCK BOILER FITTED WITH MELDRUM'S "KOKER" STOKER.

but it may be adapted to furnaces with stationary bars, with an alteration in the style of feed. With moving bars, the fuel is sprinkled over about three-fourths of the grate area, but with stationary bars the entire grate surface is fed over.

It will be noticed from the illustrations that both the "Koker" stoker and the "Sprinkler" type are fed with air from a steam-jet compressor. Mention has been made of this system in the previous pages, and it is one that deserves careful study, as its advantages are not always at once apparent. The author has known many instances where cheap fuel could not be burned either in furnaces or under steam boilers until this system had been adopted. The steam used for the steam jets should not exceed 4 per cent. of the total evaporation of the boiler, so that if 8 lbs. of water be evaporated per pound of fuel, there will be still 7.68 pounds for use outside the boiler system. We can carry the calculation a stage further. With 15 per cent. of carbon dioxide in the escaping flue gases, the volume would be 177 cubic feet per pound of fuel at 15° C., and if we credit the steam with moving the whole of it, the 4 per cent. of the fuel so employed would have moved nearly 4,500 cubic feet of air per pound of fuel used in raising the steam necessary to work the steam-jet.

But few attempts have been made to apply the system of mechanical stoking to furnaces other than those of steam boilers in this country, but the Bennis stoker has been applied to furnaces for drying grain in flour mills, and for the purpose of roasting silver ores in Australia. The Meldrum stoker has been applied to furnaces abroad for roasting gold ores, and there is no doubt that every description of furnace for burning coal could be fitted with mechanical stokers, and will be, so soon as the subject comes to be sufficiently studied by those who have to pay the coal bill.

Mechanical stoking offers a means of effecting complete combustion with the minimum of excess air, and this is no trifling consideration, as a few figures will show us. If we refer once more to page 270 Vol. I. (Table 89) we shall see that with 295 cubic feet of waste gases per pound of fuel, the theoretical initial temperature is 1,407° C., with 205 cubic feet of air, 1,968° C., while with only 166 cubic feet per pound of fuel, corresponding to 16 per cent. of carbonic acid in the products of combustion, the initial temperature is 2,366° C. Sixteen per cent. of carbonic acid in the waste gases is by no means unattainable as a general rule, and it means, *ceteris paribus*, an immense economy.

The foregoing theoretical initial temperatures of combustion are far greater than can be realised in practice—in fact, nothing like such temperatures can be attained in the ordinary way of working, except by attention to even the smallest details. In the actual zone of combustion the temperature doubtless approximates to the foregoing figures, but in the interior of a muffle, never, and only occasionally in such situations as the bed of a puddling furnace or copper smelter or steel-melting furnace.

The next step to a full consideration of this branch of our subject must be the question of chimneys, as they occupy a very important place in our legislative enactments. The Public Health Acts give control over

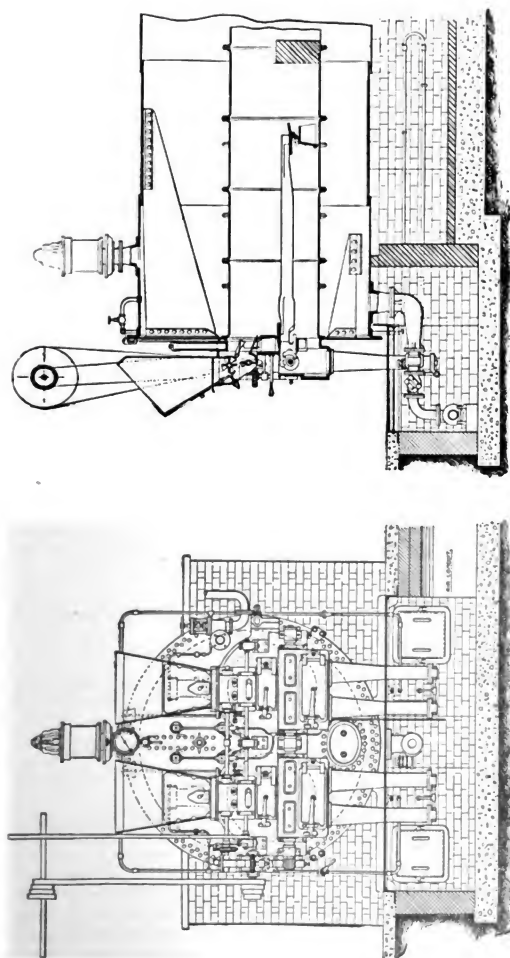


FIG. 19.—SPRINKLER STOKER ON A LANCASHIRE BOILER.
(Messrs. Meldrum Bros., Ltd.)

their smokiness, and the Alkali Acts provide that the gases or vapours leaving the chimney shall not contain more than a specified quantity of certain well-known corrosives. Nearly every manufacturer, when he contemplates the erection of a works, commences by building a tall chimney into which all the smoke and vapours of the establishment are eventually taken. The author would ask his readers to consider whether this course is a correct one, in view of the harassing by ignorant local officials and paid inspectors, who must do something to show that they have not been asleep when their pay-day comes round. Is it a proper course to squeeze all the smoke from, say, one thousand tons of coal per week, through a chimney perhaps only ten feet diameter at the summit, which can be done with a speed of only 12 lineal feet per second? A tall chimney is not absolutely necessary for draught, and it seems to the author that the best way of keeping on the right side of the Smoke Acts is to avoid putting all the smoke into one chimney. A number of smaller chimneys would do the work quite as well as, or even better than, a chimney 200 feet in height.

The question of chimney draught has been somewhat obscured by much that has been written on the subject. Some authorities tell us that the "best draught" is obtained when the temperature of the gases within the chimney reaches, but does not surpass, a certain figure. This figure has been fixed at about 300°C . (572°F .) from purely theoretical considerations, which the student may readily work out for himself.

It is well known that the velocity of gases (V) in a chimney grows indefinitely with the temperature (t) when the temperature of the air (T) remains constant, but as the gases expand the unit volume weighs less and less, so that it does not follow that the weight of the gas (P) increases in the same manner; in fact it is easy to see that the variable factor with t is not $t - T$ but $(t - T)$ divided by $(1 + at)^2$.

If we put y for $\frac{t - T}{(1 + at)^2}$ we can determine the value of t which gives a

maximum for y , by the differential equation:—

$$\frac{dy}{dt} = \frac{(1 + at)^2 - 2a(t - T)(1 + at)}{(1 + at)^4} = 0$$

from whence we get $1 + at - 2a(t - T) = 0$, and consequently:

$$t = \frac{1}{a} + 2T$$

so that a being the coefficient of expansion of gases and T the temperature of the air, P will be at its maximum when

$$t = 273^{\circ} + 31^{\circ} \text{ or } 304^{\circ}\text{C}.$$

The foregoing, however, is quite a theoretical figure, but, notwithstanding, it serves a useful purpose in directing attention to the wastefulness of sending gases into the chimney at temperatures above 300°C ., especially as is well known that a sufficient draught for nearly every purpose may

be obtained with temperatures in the neighbourhood of 100°C . Those who have witnessed the keen draught in the furnaces of a Porion evaporator, with a chimney temperature of 85°C ., would never argue as to the necessity of a temperature of 304° . What the foregoing equation does teach us, is, that there is no danger of reducing the draught of a chimney by utilising some of the heat of the escaping gases, until the temperature has fallen below 304°C ., and in practice the draught is safe at a very much lower figure. In fact, the increment of heat from 150°C . to 300°C . produces results that are not of much practical importance, as may be seen from the annexed diagram (Fig. 20), which shows the theoretical capacity of the chimney illustrated in Fig. 21.

Many books have attempted to give a formula for ascertaining the velocity of the gaseous current in chimneys, but these formulæ do not

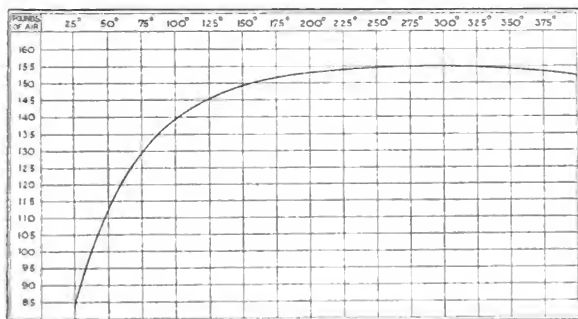


FIG. 20.—DIAGRAM OF THEORETICAL HEAT EFFICIENCY IN CHIMNEYS.

agree amongst themselves, and, as they do not take cognisance of serious physical interferences, they are quite inapplicable to the task of discovering the actual velocity of the moving gases. We may take as an instance the formula given on page 466 of Molesworth's Pocket Book for Engineering, which is

$$0.365 \sqrt{H(t - T)} = V \quad (d)$$

Where V = the velocity in feet per second ; H , the height of the chimney in feet ; and t and T the high and low temperatures respectively in degrees Fahrenheit. This formula could only give approximate figures, but as it bears no definite relationship to the actual velocity of a current of gas in a chimney of the height H and of the temperature t , the figures expressed by the formula must be used with that understanding.

It may be accepted as generally correct that no simple formula can ever give, even approximately, the actual velocity of the gaseous current

in chimneys, when only the height and temperatures are known. The only figures such a formula can give us are those which predict what the velocity *might be*, if friction and all interfering quantities could be eliminated, which is out of the question. But figures yielded by such a formula, taken in conjunction with actual measurements of the velocity, as described on page 222, *et seq.*, of Vol. I., will give a ratio, which tells us what proportion of the theoretical work the chimney is actually doing. This is a great help sometimes; and, if this aspect of the question were more thoroughly studied, the result would be a considerable saving in chimney expenditure.

Peclet and others have gone very deeply into the causes which tend to make the actual draught of chimneys so much less than that calculated by formula (e), such as the friction of the fire-bars, the friction of the gases against the sides of the flues, the loss of head due to sudden enlargement of the channel, the loss by sudden bends in the flues, and other sources, but it will be found better for all practical purposes to fall back upon the anemometer reading for the determination of actual velocities.

If we suppose friction to be entirely suppressed, the theoretical, or utmost possible velocity of a current of hot gases in any chimney, and, consequently, the volume of gases passing and their weight may be obtained by the use of the following general formulæ:—

$$V = \sqrt{\frac{2 g H a (t - T)}{1 + aT}} \quad (e)$$

$$Q = A \sqrt{\frac{2 g H a (t - T)}{1 + aT}} \quad (f)$$

$$P = \frac{.0807A}{1 + aT} \sqrt{\frac{2 g H a (t - T)}{1 + aT}} \quad (g)$$

Where V = the velocity of the hot gases in feet per second.

g = the acceleration of gravity (32.0).

H = the height of the chimney in feet.

a = the coefficient of expansion of gases.

t = the temperature of the hot gas within the chimney.

T = the temperature of the outside air.

Q = the volume of air per second in cubic feet.

A = the area of the chimney in square feet.

P = the weight of air in pounds per second.

The formula may be used on the metric system by substituting metric values throughout, or 9.81 as the acceleration of gravity and 1.293 kilos. as the weight of a cubic metre of air at 0° C.

The particulars of some chimneys with which the author has been in touch for several years may be found in Table 6, and it may be interesting to see how these formulæ compare with each other, and what is the relationship of the numbers obtained by their use, to the actual ascertained velocity in some of these chimneys.

TABLE 6.

SHOWING SOME PARTICULARS OF CHIMNEY DRAUGHT.

No.	Area in sq. ft.	Height in feet.	Temp. °C.	Velocity in feet per second.			Efficiency % Actual to Calculated
				at 15°C.	Actual.	Form. <i>d</i>	
1	36	160	176	16.0	20.0	78.8	25.37
2	415	240	132	1.2	1.4	81.7	1.71
3	33	160	215	5.0	6.5	87.6	7.42
4	78	180	304	7.8	11.0	111.7	9.85
5	98	160	157	4.4	5.3	73.7	7.19
6	50	150	121	6.0	7.0	61.7	11.34
7	145	160	104	3.0	3.4	58.4	5.82
8	16	120	107	12.0	13.8	51.1	27.01
9	9	100	269	30.0	41.0	77.7	52.77
10	42	160	166	3.3	4.0	75.9	5.27
11	35	210	177	10.2	12.7	90.1	14.09
12	38	126	38	2.8	2.9	25.9	11.19
13	132	170	160	4.8	5.8	76.6	7.57
14	78	270	65	10.0	10.8	56.9	18.98
15	64	200	215	20.0	26.0	97.8	26.59
15 ^a	64	200	227	18.0	23.7	100.4	23.60
16	38	150	104	4.7	5.4	56.6	9.54

Let us take Nos. 2, 4, 9, 12, 15, and 16 of the table, and calculate the velocity by the formulæ *d* and *e*, already given, for each of them. These have been selected as giving extremes of temperature variation and actual speed, and the result of the comparison may be seen in Table 7.

TABLE 7.

CHIMNEY DRAUGHT. SHOWING THE RESULTS IN EXTREME CASES.

No.	Chimney measurements.		Actual velocity. Feet per second.	Feet per second. Calculated by formula.		Efficiency from Table 6.
	<i>H</i> feet.	<i>t</i> °C.		<i>d</i>	<i>e</i>	
2	240	132	1.4	81.7	78.8	1.71
4	180	304	11.0	111.7	102.0	9.85
9	100	269	41.0	77.7	75.0	52.77
12	126	38	2.9	25.9	25.3	11.19
15	200	215	26.0	97.8	94.2	26.59
16	150	104	5.4	56.6	54.7	9.54

An examination of Tables 6 and 7 will bring out some important particulars, the chief of which is that an efficiency of 50 per cent. of the calculated velocity can be attained under certain conditions. It will also be seen that neither a high temperature nor an excessive height of chimney is necessary for securing an adequate draught, as, judging from the work actually performed in No. 9, a chimney cannot be styled overworked unless the efficiency actually obtained is greater than 50 per cent. If we fix 50 per cent. as a basis of comparison, chimney No. 4 would do five times the work it was actually doing, while No. 12 would do 4.55 times the work it was doing under the conditions recorded in the Table. No. 2, which was a chimney 240 feet in height, possessed an actual velocity of gaseous current of 1.4 feet per second, but the efficiency being 1.71, it would appear probable that this chimney would be capable of doing thirty times the work it was ordinarily called upon to do. Contrast the foregoing with the figures connected with No. 9 on the list, which is a chimney but 100 feet in height, and yet the gases have an actual velocity of 41.0 feet per second.

The figures relating to numbers 15 and 16 of the table afford some interesting comparisons. The former was the main chimney of the works, but as all the processes carried on had gradually but extensively increased in magnitude, there arrived a time when this chimney was deemed inadequate to do the work required of it. It is not on record how this decision was arrived at, but after some consideration another chimney (No. 16) was built, to which some of the furnace flues from the old chimney were transferred. In the days when the old chimney (No. 15) had all the work of the establishment to do the ratio between actual and calculated velocity stood at 26.59 per cent. and the volume of the gases emitted by the chimney, calculated to the temperature of 15° C., amounted to 1,280 cubic feet per second. When a portion of the gases was transferred to chimney No. 16, we shall find that though the temperature of the remaining gases had risen slightly, their velocity had decreased, and the efficiency had also decreased from 26.59 to 23.60.

Under the original conditions No. 15 chimney was passing 1,280 cubic feet per second, and when both chimneys (Nos. 15* and 16) were employed to perform the same work, they were passing—

No. 15* chimney (at 15° C.)	..	..	1,152	cubic feet.
No. 16 do. do.	..	..	178	..

Total for both chimneys .. 1,330 ..

a number sufficiently near to the former to indicate that the fault was not with the chimney, but probably in the flues. The author would hesitate in saying that any chimney was overworked, unless it showed a greater efficiency than 50 per cent. of the theoretical figures.

Some reference must again be made to No. 9 of the Table. This was a chimney of very small sectional area, being only three feet square internally at the base, where the walls were three brick lengths in thickness. Long narrow flues ran into this chimney from every portion of the

works, new plant being added from time to time, until it was manifest that no more air would enter at the furnace ends. What the velocity of the chimney gases was at that time there is no record, but information that is available in another direction is of the greatest interest. A new and much larger chimney was decided upon, together with a large main flue, into which the shortened narrower old flues were collected. This main flue was 5 ft. \times 4 ft. internal dimensions; it was finished long before the new chimney was completed, and in the meantime was connected up to the chimney No. 9 of the table. This flue alteration so much improved the draught as to render the larger chimney unnecessary. After the alterations just described had been in working order for several weeks, the tests recorded in the table were made. How much nearer the theoretical efficiency could have been approached it is difficult to say without actual experience, but the figures have shown that when friction is reduced to a minimum over fifty per cent. of the theoretical velocity may be attained.

The student must not, however, fall into the error of supposing that high velocities have no drawbacks; as the velocity increases so the friction becomes greater, and, as for a certain volume of gas, the velocity can be regulated by the area of the chimney, it is better to so proportion this area that the speed of the gaseous current does not exceed ten feet per second, at the temperature of the hot gases.

If we again refer to formula (e) page 48, we shall find that

$$\frac{H a (t - T)}{(1 + a T)} \quad (h)$$

expresses the height of the column of warm air producing the motive force which is an elaboration of the simple letter h in the ordinary dynamic formula

$$v = \sqrt{2 g h} \quad (i)$$

For all practical purposes, including that of ascertaining the velocity of warm air in flues and chimneys, the quantity (h) cannot be substituted for the h in the general dynamic formula, (i) but the value of h must be measured in some mobile fluid, and this can then be calculated to air column. The method of measuring the head h in a column of liquid equal to that of the sp. gr. of water has been given in detail on page 222 of Vol. I., and to this the student is once more referred.

Enough has been said upon the subject of chimney draught, and its bearing upon the construction of chimneys and the flues leading to them, so that we may now turn our attention to some points affecting the stability of tall chimneys.

During severe storms many tall chimneys have been demolished. Not only have unsound structures perished, but seemingly well-built chimneys have succumbed to the fury of the storm. It is difficult to form any accurate estimate of the wind pressure exerted during storms recorded many years back, as the accuracy of the earlier instruments is not above suspicion, but it is generally granted now that the large Kew pattern

Robinson anemometer gave readings about 30 per cent. in excess of the true velocity. Moreover, these instruments gave no indication of the strength of "gusts," and the pressure-plate anemometers which did, read up to 70 per cent. or 80 per cent. too high.

As a result of the investigations of the Wind-Force Committee of the Royal Meteorological Society, a new and reliable self-recording anemometer has been designed and perfected, and is rapidly coming into use at the best observatories and meteorological stations, having been adopted by the Government Meteorological Office. It is known by the name of Dines's Pressure-tube Recording Anemometer. By its use hourly totals exceeding 70 miles are found to be extremely rare, but it has also taught us that the rate of movement during the strongest momentary gust in a gale may exceed 100 miles per hour (147 ft. per second), especially in the vicinity of obstructions which break up the wind into more pronounced gusts and lulls, at, or not far from, the sea on an exposed coast. It is now conceivable that at a distance of several feet above the roof of a long building facing the sea, or where gaps converge, the 100 miles rate may be considerably exceeded.

If, however, we may not quote ancient figures for wind velocity or wind pressure, we have some recent figures that are reliable. On the morning of February 27th, 1903, a terrific gale blew over the western shores of England and Wales, and did much damage from Penzance in the south to Barrow-in-Furness in the north. On the Leven viaduct, nine miles from Barrow, a railway train was blown over during the terrific hurricane that prevailed, and several lives were lost in consequence. Many of the records of velocity and wind-pressure published in the daily press on the day after the storm should be accepted only with great caution, as in some very exposed situations during the gale, the non-oscillating pressure-plate maximum anemometer did not quite record 30 pounds pressure on a plate one foot in area.

On an exposed spot near the sea, at Connor Downs, near Hayle in Cornwall, a velocity of 100 miles per hour was registered on one of the old instruments during the above storm, which would most probably be equal to 66 miles on the true scale, though there may have been gusts at 100 miles. Near this spot a large factory building was demolished, the roof being blown off and the walls thrown down. Close by, and fully exposed to the storm, stood a circular chimney that had just been erected from the author's designs, but, though the mortar was not fully set, the structure was not in any way affected by the storm. A similar chimney is shown in Fig. 21 with all particulars respecting it.

If we turn to the formula for wind pressure given on page 315, Vol. I., we shall find it expressed as:—

$$P = \frac{w v^2}{g} \quad (j)$$

which is that given in most engineering text books. The author has long had a suspicion that this formula was incorrect, and that it should read :

$$P = \frac{w v^2}{2 g} \quad (k)$$

but having no means at hand to investigate the matter, preferred to follow the old formula as being on the safe side for construction. There is no doubt now that the old formula (*j*) is incorrect and that the new (*k*) should be followed, but whether the denominator is correct in fact, as $2g$, or whether it should be written as $g + R$, R representing a definite resistance equal to g in magnitude, is a matter for further investigation. This is also proved by the official experimental investigations of the Royal Meteorological Society, which show that the old formula for wind pressure must be replaced by:—

$$P = 0.003 V^2 = \text{pounds per sq. ft.}$$

V^2 being reckoned in miles per hour. This differs but little from formula (*k*), and it is probable that further investigations will bring them both into line. If then we allow a velocity of 100 miles per hour, this will produce a pressure of 30 pounds per square foot.

For safety, economy, and neat appearance no other form of chimney can equal the circular shaft, and in order to set this out plainly, let us compare a circular shaft with a square chimney of approximately equal capacity, both of which were designed and carried out by the author.

The square chimney, measured inside the brickwork, was 9 ft. square at the base, and 8 ft. 6 in. square inside at the summit, the outside measurements being 15 ft. and 10 ft. 9 in. respectively. The circular shaft measured 15 ft. 6 in. outside diameter at the base and 11 ft. 6 in. at the summit, the internal dimensions being 11 ft. and 9 ft. 3 in. respectively. Both chimneys were of the same height, viz.: 150 feet.

The formula giving the force of wind necessary to overturn any square chimney is expressed as follows:—

$$F = \frac{(W + ca) \times d}{A \times e \times 2} \quad (k)$$

Where F = the overturning force in pounds per square foot.

W = the total weight of the brickwork in pounds.

c = the cohesive force of the mortar* in lbs. per sq. in.

a = area of section of the brickwork at base, in sq. ins.

d = diameter of circular, or side of square, chimney.

A = area of one side of the chimney, in square feet.

e = height of centre of gravity, in inches above ground.

In the two chimneys under consideration, the following values can be given to the above:—

	Square.	Round.
W	1,535,250	1,080,367
ca	1,244,160	809,568
d	180	186
A	1,931	2,025
e	852	864

* The cohesion of good old mortar exceeds 60 lbs per sq. inch.

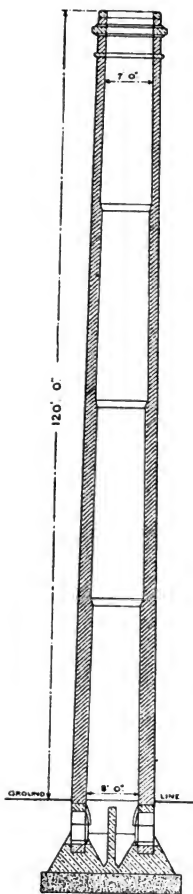


FIG 21.—
CHIMNEY—SECTION.

so that for the square chimney

$F = 155$ lbs. per square foot,
as the wind pressure necessary to overturn the structure. A similar calculation applied to the circular shaft gives 100 lbs. as the value of F ; but, as the pressure exerted on a cylinder by the wind at a given pressure is only one-half of that exerted on a plane surface of similar extension, it is seen that the overturning force

$$F = 200 \text{ lbs. per square foot}$$

for the circular chimney. So that this latter is lighter, safer in storms, and, as a matter of fact, will pass more hot gases through it, under similar conditions, than the square chimney.

As to cost, the square chimney contained 13,350 cubic feet of brick-work above the ground level, while the round shaft contained only 9,394 cubic feet, and as they cost £716 and £528 respectively, all costs included, it is presumed that but few would prefer the square chimney if they had once studied the question. Some particulars of the construction of the circular chimney mentioned on page 52 may be seen in Fig. 21. It measures 8 ft. internal diameter at the base and 7 ft. at the summit, standing 120 ft. above the ground. It contains 112,000 bricks, all made to templates, and is capable of withstanding a wind pressure of 130 lbs. per square foot. The *theoretical* power of this chimney is shown upon the diagram Fig. 20, but its maximum working capacity should not be estimated at more than one-half of those figures. If the student will work out these figures he will find that the theoretical maximum is reached when 155 lbs. of air are passing per second, and as 20 lbs. of air are necessary for the combustion of one pound of coal, the chimney is *theoretically* capable of dealing with 7.75 lbs. per second, or two thousand tons of coal per week. This is what formula (g), page 48, tells us, and the author believes it quite possible to enable such a shaft to deal with the products of combustion from one thousand tons of coal per week, if the flues be of ample size and well arranged.

To look at the matter, however, from a purely practical standpoint, such a chimney

as the foregoing should only be called upon to take the products of combustion from 400 tons of coal per week, as at this rate the gases would be travelling in it at a velocity of ten feet per second, which is what the author would call the normal rate for such a chimney.

In connection with this subject, the *Memoires de la Société des Ingenieurs Civil* several years ago gave some particulars of the oscillations of a chimney near Marseilles, during a violent storm. The stack was 118 ft. high, and 5 ft. in external diameter at the top. The oscillations were determined by observing the motion of the shadow of the chimney, and in this way the greatest oscillation was found to be twenty inches. The *Oesterreichische Zeitschrift für Berg und Hütten*, referring to another chimney 164 ft. high and 6.5 ft. internal diameter at the top, states that repeated observations with a theodolite showed that the oscillations did not exceed 6½ ins.

There are two matters in connection with chimney work that require some consideration, and they may be studied together. These are, the utilisation of the waste heat, and the question of smoke, problems which many inventors have endeavoured to solve.

If we turn to page 262, Vol. I., it will be found that about 24 per cent. of the total heat of the fuel passes away to the chimney from ordinary steam boilers, and when this heat is passed through a suitable economiser, it yields up about one half to the water that is circulating in its interior, reducing the temperature of the gases from 400° C. to 167° C., or to the temperature of 90-lb. steam. As 12 per cent. of the total heat of the fuel does not remain for utilisation, seeing that the temperature to cause the draught has to come from it, it will be seen that there is not much scope for further improvement. In forming this conclusion, one is influenced almost entirely by practical considerations, the chief of which are, that when heat exchanges have to be made at low temperatures, very extended surfaces must be employed, and these are costly. The quantity of heat remaining available after that required for providing the draught must, of course, depend upon what is considered necessary for that draught. Table 6, page 49, shows us that a chimney (No. 12), the gases in which only reached a temperature of 38° C., had an actual velocity of 2.9 feet per second, while the theoretical formula showed that it might possibly become 25.9 feet. Chimney No. 14 possessed a temperature of 66° C., with a velocity of 10.8 feet per second, and a theoretical velocity of 56.9 feet, so that if we consider the temperature really necessary for chimney draught to be 104° C., ample allowance will have been made. The necessary temperature has been fixed at above the boiling point of water, so as to ensure that no deposition of moisture takes place within the flues or within the chimney. In the Porion evaporator, where the chimney vapours reach only 86° C., the flues are always wet, and the chimneys themselves are likewise damp, so that their construction has to be modified accordingly. The draught will then require 8 per cent. of the heat of the fuel, leaving only 4 per cent. for further utilisation. With coal slack at 8s. 4d. per ton, this 4 per cent. means 4d. per ton of slack—it is easy to see what expenditure is worth it.

The foregoing would show us what is the proper course to take in dealing with the waste heat from boiler settings where economisers are used. It is to place the superheater for the steam between the boiler and the economiser, and to extend the latter so that the gases escape from it into the chimney at a temperature of about 104°C . The construction of the superheater, when placed in such a position, would have to be most carefully considered, but economiser practice will be found a very useful guide.

When we come to deal with the waste heat from furnaces, we have a problem of quite another character. Very often 95 per cent. of the heat of the fuel is found escaping into the chimney, or eight shillings' worth of each ton of coal burned, at 8s. 4d. per ton. Surely there is a stimulus here for invention. But with furnace gases, especially those from chemical furnaces, the presence of profligate associates renders the work of utilisation extremely uncertain. The author has seen an economiser ruined by an attempt to utilise the waste heat from salt-cake furnaces, the damage arising from the small quantity of hydrochloric acid gas present in the products of combustion.

It is when we come to utilise the waste heat from flues that we discover the evil influences of black smoke or soot. Soot is a splendid non-conductor, and if economiser pipes become coated with it scarcely any heat will pass into their interior. This is why all economisers are fitted with automatic scrapers, to remove the soot as it collects. These work well enough in a temperature of 400°C . or less, but become quite unworkable at a red heat.

Siemens showed us many years ago how we might profitably utilise the waste heat from high temperature furnaces by a system that has been extensively adopted. Instead of passing the red-hot or white-hot gases direct to the chimney, Siemens passed them first through what he called a "regenerator," which was a rectangular chamber filled with pigeon-holed brickwork, a portion of which may be seen in Fig. 10. In this way the brickwork became highly heated, when, by an arrangement of dampers, the course of the draught was changed, and, the regenerators being worked in pairs, the hot gases were turned through a cooler regenerator, while the air necessary for combustion was made to enter the hot regenerator on its way to the combustion chamber of the furnace. This reversal of the direction of the current, effected once in each half-hour, kept the regenerators at one uniform heat, and rendered the working very satisfactory. In some furnaces both the air and the gas were superheated in this way, while in others only the air was thus raised in temperature. It has been found in practice that six square feet of firebrick surface in the regenerators are necessary for the absorption of the heat from each pound of coal burnt per hour, when the gases leave the furnace at about $1,500^{\circ}\text{C}$. It will be obvious that this pattern of superheater could not be used with gases loaded with dust, which would speedily choke up the interstices between the bricks, and thus upset all the arrangements.

In heating air, the student will no doubt remember that it is diathermanous and that radiant heat passes through it without raising its tem-

perature appreciably, so that air must be heated by actual contact with the hot surface. The addition of steam to air diminishes its diathermanous power, so that a mixture of steam and air is more easy to superheat than air alone. Steam superheaters are not difficult to design, the only points to consider being the allowance to make for expansion, and the surfaces requisite to give the desired temperature. In air-heating it is necessary to arrange the apparatus so that the current is continually being broken up and made to impinge upon the hot surface. This is especially necessary for pipe apparatus.

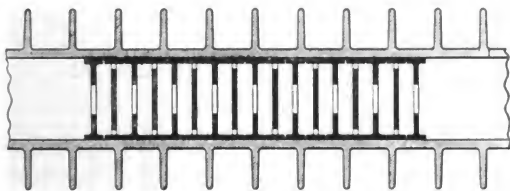


FIG. 22.—AIR SUPERHEATER PIPE.

A very perfect apparatus for superheating air, and in fact for superheating steam also, consists of a gilled pipe four inches in diameter, shown in section by Fig. 22. It is filled with a series of stops with central and peripheral apertures placed alternately, so that the gaseous current is continually being forced into contact with the heated pipe. As it is necessary to keep the heating pipe clean and free from any deposit of soot, coke is used as the heating medium. Further details of these stops may be seen in Fig. 23.



FIG. 23.—STOPS FOR AIR SUPERHEATER.

Another form of superheater for steam, when it is employed for such purposes as the distillation of glycerine, is that made by Messrs. Werner Pfeleiderer and Perkins, Ltd., and shown in Fig. 24, from which it will be seen to consist of a wrought iron coil, cast in a circular ring of cast-iron. This cylinder forms the furnace of the superheater, and contains the combustible, which in burning, radiates its heat to the embedded coil, and to the steam passing through it.

It may be mentioned here that Green's economiser, already described in Vol. I. (page 273) is now employed to utilise the waste heat in the flue gases from steam-boiler fires after these have passed through the ordinary economiser, and this is one way of exercising the economy already advocated, whenever a supply of hot-air is needed. The air heating pipes are placed in the flue after the ordinary water-heating economiser, and the tubes are kept free from soot by scrapers in the same manner as the foregoing. The cold air is forced through the top branch pipe of the system by means of a fan, and passes down one half of the first group of tubes, then up the second half, and so on throughout the system, the air leaving the apparatus at about the temperature of boiling water.

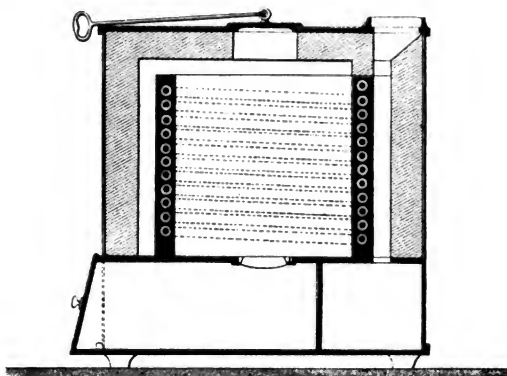


FIG. 24.—STEAM SUPERHEATING COIL.

At one works where the foregoing system is carried out, the installation consists of five Lancashire boilers consuming 132 tons of coal per week of 56 hours, possessing a grate surface of 228 square feet; a water-heating economiser of 320 pipes and an air heater of 192 pipes fed by a Sturtevant No. 7 fan running at 1,140 revolutions per minute. The temperature of the gases leaving the boilers and entering the water economiser averages $392^{\circ}\text{C}.$, leaving at $214^{\circ}\text{C}.$, at which latter temperature they enter the air heating installation. Here, the temperature of the chimney gases is reduced to $187^{\circ}\text{C}.$, while the air is heated from $23^{\circ}\text{C}.$ to $99^{\circ}\text{C}.$ The volume of air heated amounts to 170,846 cubic feet per hour, or nearly 6.0 tons, and has absorbed the heat from 33 lbs. of coal. The air pressure at the inlet is 2.13 inches of water.

In connection with the question of soot, some mention must be made of the attempts to suppress the black smoke from chimneys. The problem has been attacked from two opposite points: one, in which the aim has

been to prevent smoke leaving the furnace, while in the other it has been attempted to wash the smoke after it has left the furnace and has done its work. The former is the more rational mode. A complete cure for black smoke from steam boiler fires lies in the rational application of mechanical stoking. By this means the fuel is fed into the fireplace almost continuously in small quantities at a time, and there is always enough air present in the atmosphere of the furnace, and sufficient temperature, to completely consume the volatile portion of the fuel as it is gasified. Contrast this with the ordinary mode of hand-firing. The furnace door is thrown wide open, admitting a terrific volume of cold air, and stopping for the time being the flow of air through the bars of the grate. The fire is usually a thin one, from five inches to six inches thick, and on to this the workman throws about ten or a dozen shovelful of moist slack. Is it to be wondered at that smoke appears in the chimney when the furnace door is closed? The combustion of fuel requires air, heat, and time, and these three conditions must be properly proportioned. If we take a shovelful of slack to weigh 10 lbs., a boiler fire burning 40 tons per week will, roughly, consume one shovelful per minute. If this quantity could be thrown on each minute without unduly opening the fire door, there would be no smoke, but if a dozen shovelful be put on every quarter of an hour, no amount of draught and no amount of carefulness will prevent smoke from being formed.

When furnaces, other than those belonging to steam boilers, are considered, one feels bound to admit that there are patterns that cannot be smokeless at all times when solid fuel is employed. With gaseous fuel, especially producer gas, all operations can be rendered smokeless with certainty, and it is almost certain that considerable extension of this mode of heating will take place in the near future.

Let us now see what are the difficulties in the way of washing out the soot from chimney gases when once black smoke has been produced. In the first place, the gases must be thoroughly moistened, and this means a reduction of their temperature to a point below 100°C . In fact, if red-hot gases are passed into a chamber filled with water-spray, the instant they come in contact with the excess of water, the temperature is reduced to 86°C ., and the gases leave the chamber super-saturated with water-vapour at that temperature. Then again, the quantity of water required to replace the evaporation is so enormous as to place the method outside the pale of practical consideration. The heat from a ton of slack passed into a chamber of this kind will evaporate no less than 10 tons of water, and this would be the quantity of water used when dealing with the waste heat from a reverberatory furnace. With steam boilers the matter is not so serious if the waste gases have been reduced in temperature by a superheater and economiser, the 8 per cent. necessary to produce the draught mentioned on page 87 being only capable of evaporating 32 tons of water from each boiler weekly, but, as already set forth, there should be no need to wash the gases from steam boiler fires, unless, at some future time, steam raisers be prohibited from putting sulphurous acid gas into the atmosphere. This may

come about, as 100 tons of ordinary boiler coal give out about two tons of sulphurous acid gas.

Turning once more to furnaces, there are a few details of construction that should not be overlooked. The first is the fusibility of the materials of which they are constructed, and next the expansion and contraction which such materials undergo.

All furnaces are constructed of fire-bricks, except in those parts not in contact with the high temperature. The fire work is generally put in as a lining and not bonded in to the common brickwork, in order that a new lining may be easily put in when the old one is worn out. The various qualities of fire bricks have already been described on page 107 *et seq.* (Vol. I.), so that it only remains to show how the furnace is bound together, and the reason for thus binding it. If we refer to Figs. 3 and 25, which show a section and side elevation of a black-ash furnace, we shall see that the sides are braced with flat iron bars running the whole length of the furnace. The top and bottom bars are intended to distribute the thrust of the arch and the bed respectively, and are held up against the furnace side by old railway metals



FIG. 25.—SHOWING THE BRACING OF AN OPEN CALCINER.

or backstays (generally called "buckstuffs") connected together across the top of the furnace with "tie rods," the ends of which are either screwed and tightened up with nuts as shown in Fig. 25, or the ends are made to terminate in loops which are afterwards tightened up with an iron wedge. Intermediate between the top and bottom bands may be seen a central bar of flat iron; this is not always used, but it doubtless adds to the life of the furnace. The thrust of the arch is considerable, as fire-arches are made as flat as possible, and this thrust is increased as soon as the furnace gets warm, so that the full tightening up of the tie rods should not be done until the furnace has become nicely warmed through. At one time the lower end of the backstay was held tight in loops, one end of which was bent up and imbedded in the solid brickwork of the furnace, but this was given up for the continuous tie rod running from side to side of the furnace, the ends being furnished with loops into which the feet of the backstays were firmly fixed. The method preferred by the author is to wedge up the foot of the backstay in an excavation 18 inches below the floor line and 18 inches square, and to fill in the excavation with cement concrete.

Some furnaces are braced and entirely covered with cast-iron plates forming a kind of shell for the furnace, and doubtless such furnaces remain

longer in repair so far as the side walls are concerned than when only partially covered with flat plates, but the vulnerable parts are the furnace and front portion of the arch, to which such a method of bracing does not add any longer life. Moreover, the radiation from an iron-cased furnace is much greater than when braced as shown in Fig. 25.

The necessity for bracing the furnace upon the bed courses does not at first sight become apparent, but in practice it is found that though the bed is solid, the substance undergoing treatment finds its way between the joints of the brickwork and tends to gradually force the bricks asunder.

The effect of bracing a furnace entirely with iron plates, in its influence upon radiation, may be seen by a study of iron-cased pyrites burners. The radiation tests which follow here were made on ordinary cast iron burner fronts by Mr. John Hargreaves, and communicated by him to the author. The burners or kilns were built of gin. brickwork, the iron fronts being 1 in. in thickness, and the area of each front (excluding the sliding door) was 30.65 square feet. Each kiln was charged with 8 cwts. of pyrites every twenty-four hours. The kiln front was tested at eleven different places to obtain the average radiation, the results of each test being set forth in the following table :—

TABLE 8.

SHOWING THE LOSS OF HEAT FROM PYRITES-KILN FRONTS.

No. of Experiment	°F. of water before Experiment.	°F. of water after Experiment.	Time in Experiment.	°F. in ten minutes.	B.T.U. per sq. ft. per hour.
1	56.0	65.2	5	18.4	368
2	60.5	69.0	5	17.0	340
3	65.5	72.0	5	13.0	260
4	56.6	62.0	5	10.8	216
5	49.5	58.3	5	17.6	352
6	58.5	73.0	5	29.0	580
7	53.0	62.1	3	30.3	606
8	62.5	71.1	3	28.7	574
9	51.1	61.5	4	26.0	520
10	62.0	74.0	2	60.0	1200
The door.	50.0	80.0	2	150.0	3000

Each burner front would, therefore, radiate per hour :—

$$\begin{aligned}
 501 \times 30.65 &= 15,355 \text{ British thermal units.} \\
 \text{Door, } 3000 \times 1.41 &= 4,230 \text{ „} \\
 \hline
 19,585 \text{ „} &= 10,880 \text{ C.H.U.}
 \end{aligned}$$

As the heating power of common furnace slack is about 6,000 Centigrade heat units, the heat lost by radiation from one burner front must be not less than :—

$$\frac{10,880}{6,000} = 1.8 \text{ pounds per hour.}$$

or, on a set of forty burners, the heat produced from the complete combustion of 17 cwts. of slack per twenty-four hours.

The heat lost by radiation and other influences from pipes and heated surfaces generally, may in most instances be approximately calculated, quite nearly enough for all practical purposes, by means of formulæ given us by Peclet, Dulong, and others, who have minutely studied the subject. There are three main losses we have to consider in working out problems of this kind: *a*, the loss by radiation simply; *b*, the loss by contact with air, and *c*, the loss by conduction. It must not be forgotten that these losses are much greater at high temperatures than at low temperatures, which makes the calculations rather more uncertain and intricate, but when it is appreciated that the results obtained by these formulæ can never be more than an approximation to the truth, and only employed as a general guide to practice, they will have done all that may be fairly expected of them.

The Loss by Radiation.—As all bodies radiate and absorb different quantities of heat, it may be as well at the outset to give in tabular form (after Peclet) the values of some of those substances with which the Chemical Engineer is daily brought in contact, the numbers being the C.H. units emitted or absorbed per square foot per hour for a difference in temperature of 1°C.

TABLE 9.

SHOWING THE RADIATING AND CONDUCTING POWERS OF SUBSTANCES.

Substance.	Specific heat.	Radiating capacity. R.	Conducting power. C.
Copper	0.0921	.0327	515
Wrought iron	0.1138	.5698	233
Cast iron	0.1400	.6480	227
Zinc	0.0955	.0491	225
Lead	0.0314	.1328	113
Stone	0.2204	.7358	13.7
Glass	0.1977	.5948	6.60
Brickwork	0.1851	.7400	4.83
Deal	0.6510	.7358	1.37
Kieselgühr	0.2242	.7400	.87
Sawdust	0.6510	.7215	.52
Cotton wool	—	.7500	.32
Soot	0.4596	.8196	.31

Before proceeding further, it will perhaps be profitable to call attention to some peculiarities of the various "heat units," the differences between which have served to mystify many a student in his elementary days, and also many a professional man who only takes up the subject at intervals.

In the third column of Table 9, denoting radiating capacity, the figures represent the numbers of Centigrade heat units given out by one square foot per hour from the material that is losing heat to a receiving medium, one

degree cooler than itself. It will be seen upon close examination of the question, that for both B.T. units and C.H. units the numbers are similar, while they will be smaller for the metric "calorie." The table (g) shows that a square foot of wrought-iron will radiate 0.5698 B.T. units per hour for a temperature difference of 1° F., or 0.5698 C.H. units per hour for each 1° C., and it will be useful at the same time to give Peclet's figures expressed in calories per square metre, which are 2.77 cal. As will be shown presently, these numbers are too low when the temperature difference exceeds 10° C., and require multiplying by a coefficient which increases with increase of temperature, but for the sake of simplicity in this explanation, the correction will not be introduced now.

Let us now suppose a cubical vessel made of wrought-iron, each face measuring one square foot, and the vessel filled with boiling water, the temperature of which is maintained constant. The temperature of the air being 60° F., or 15.5° C., what is the heat radiated from the square foot of surface, or in other words how much water will the radiated heat raise 1° in temperature? Peclet tells us that one square metre will emit 2.77 calories, which is 0.259 cal. for each square foot. As each calorie represents one kilogramme of water raised one degree Celsius, we have

$$(a) \quad (100-15.5) 0.259 = 21.88 \text{ calories,}$$

which is equivalent to 86.6 pounds of water raised one degree Fahrenheit.

Turning now to Centigrade heat units (C.H.U.), and to the numbers given in Table 9, we shall find that:—

$$(b) \quad (100-15.5) 0.5698 = 48.15 \text{ C.H. units,}$$

which is also equivalent to 86.6 pounds of water raised 1° F.

We may now turn to the British thermal unit itself, when we shall find that:—

$$(c) \quad (212-60) 0.5698 = 86.6 \text{ B.T. units}$$

or pounds of water raised 1° F.

It will therefore be seen that when the calorie, the C.H. unit, or the B.T. unit is used as an absolute quantity, the foregoing ratios must be strictly remembered. In actual heat emitted by the radiant, the calorie is 2.2 times as great as the Centigrade heat unit, and 3.96 as great as the British thermal unit. The bearing of this upon other heat problems may be studied with reference to page 61, and also to page 246 of Vol. I.

Again, when Column C of Table 9 is considered, Peclet gives the loss of heat from one square metre of cast-iron, one metre in thickness, as 28 calories for 1° C. of temperature difference. In this country, the conducting power is always expressed in units per square foot for one inch in thickness, so that Peclet's figure becomes:—

$$\frac{28 \times 2.2 \times 1000}{25.4 \times 10.7} = 227 \text{ C.H. units,}$$

which will also be found the number for British thermal units per square foot.

When there is only a small difference between the temperature t of the radiant and the temperature T of the absorbing body or recipient, the formula

$$R' = R (t - T) \quad (l)$$

will show us, with a fair degree of accuracy, the heat units lost by radiation for each square foot of surface, but when the differences between t and T are greater than 10°C. , a more complex formula should be followed. Dulong has carefully experimented with radiation losses at high temperatures, and has found that the loss of heat under these conditions increases in a much more rapid ratio than that of $t - T$. Peclet and Dulong together have given us a formula for these high temperatures which, when divested of its complexity, may be stated as:—

$$R'' = \frac{124.72 \times 1.0077^{\frac{t}{T}} \times (1.0077 - 1)}{T} \quad (m)$$

where R'' is the *ratio* of the loss of heat under the higher temperature, t the temperature of the absorbing body, and T the excess of temperature expressed in degrees Celsius. This, used to correct the simple formula (l), will be sufficient for all practical purposes. Dulong's figures for high temperature radiation are enormous, the value of R'' being 3.0 for 235°C. , 12.0 for 500°C. , 150.0 for 870°C. , 1160 for 1216°C. , and 4600.0 at 1416°C. Perhaps some further light will be thrown on these figures some day.

The foregoing formula (m) cannot be solved without the use of logarithms, and therefore the following table is given (after Peclet) for the more useful temperatures met with in everyday work. If the higher temperatures are required, the formula must be resorted to.

TABLE 10.

SHOWING RATIOS TO BE USED IN CONNECTION WITH TABLE 9. (Peclet).

$t-T$	R''	R'''	$t-T$	R''	R'''
10°	1.12	—	140°	1.92	1.74
20°	1.16	1.11	150°	2.01	1.77
30°	1.20	1.22	160°	2.12	1.80
40°	1.25	1.31	170°	2.22	1.82
50°	1.30	1.37	180°	2.32	1.85
60°	1.36	1.43	190°	2.44	1.87
70°	1.42	1.49	200°	2.55	1.89
80°	1.48	1.53	210°	2.68	1.92
90°	1.54	1.57	220°	2.81	1.94
100°	1.61	1.62	230°	2.95	1.96
110°	1.68	1.66	240°	3.11	1.98
120°	1.76	1.68	250°	3.30	2.00
130°	1.84	1.71	500°	12.00	2.34

Loss by Contact with Air.—The loss of heat that takes place by reason of the contact of the heated body with air, depends in a great measure

upon the form of its surface : a cylinder, a sphere, or a plane surface emitting different quantities when at similar temperatures. The nature of the material does not seem to be of much moment, as iron, firebrick, glass, stone, or wood will lose the same number of heat units under the same conditions of temperature. We are considering now small differences, and up to 10°C . we may take the loss as fairly expressed by the following formula :—

$$A' = A \times d = \text{C.H.U.} \quad (n)$$

where A' expresses the heat units lost by contact with air per square foot per hour ; A the loss for 1°C . ; and d the difference of temperature between the heated body and the air in contact with it.

The actual loss of heat from a plate one foot square has been shown by experiment to amount to 0.5945 C.H. units per hour for 1°C . of temperature difference, a number which in practice may be shortened to 0.6 C.H.U.

If the height of the vertical plane exceeds one foot, the loss per square foot per hour is less than that expressed by formula l , and the following formula must be used to determine the value of A :—

$$A = 0.361 + \left(\frac{0.233}{\sqrt{H}} \right) \quad (o)$$

A being the loss in C.H. units per square foot per hour for 1°C . in temperature difference, and H the height of the vertical plane in feet.

For a horizontal cylinder (such as we may imagine the burner pipe leading the hot gases from a set of pyrites kilns to the de-nitrating tower to be), the following formula (p) will give us the C.H. units lost per square foot per hour for a temperature difference of 1°C ., r being the radius of the cylinder in inches :—

$$A = \frac{0.307}{r} + 0.421 \quad (p)$$

For a sphere the rule becomes :—

$$A = \frac{1.0476}{r} + 0.3634 \quad (q)$$

When we come to consider vertical cylinders, a knowledge of the height in inches h , and the radius r , measured also in inches, will enable us to calculate the loss of heat by air contact, by applying the following formula, A being the loss in C.H. units per square foot per hour, as before :—

$$A = .2044 \left(0.726 \frac{0.2163}{\sqrt{r}} \right) \left(2.43 \frac{5.49}{\sqrt{h}} \right) \quad (r)$$

The following table (11) has been calculated by means of formulae p and r , and doubtless will be found useful, as the loss of heat from vertical and horizontal cylinders in units per square foot per hour for 1°C . difference in temperature, can be obtained from it by simple inspection.

TABLE 11.
SHOWING THE LOSS OF HEAT FROM CYLINDERS.

Diam of cylinder	Horiz- ontal cylinder	Vertical cylinders. Values of A for height in ft.							
ins.	A.	1	5	10	20	30	40	50	
2	·7280	·7733	·6046	·5654	·5363	·5237	·5164	·5123	
4	·5745	·7213	·5639	·5273	·5002	·4885	·4816	·4769	
6	·5230	·7016	·5491	·5139	·4874	·4760	·4693	·4648	
8	·4978	·6846	·5353	·5005	·4747	·4636	·4571	·4526	
10	·4824	·6727	·5288	·4946	·4691	·4581	·4516	·4472	
12	·4722	·6683	·5224	·4886	·4634	·4526	·4462	·4418	
18	·4551	·6550	·5121	·4788	·4542	·4446	·4374	·4330	
24	·4466	·6471	·5058	·4730	·4487	·4382	·4320	·4378	
36	·4381	·6377	·4985	·4662	·4422	·4318	·4225	·4183	
48	·4338	·6255	·4912	·4594	·4357	·4254	·4130	·4088	

Dulong found in his experiments, especially at high temperatures, that the heat losses by contact with air increase more rapidly than the simple ratio of increase of temperature, but to nothing like the extent as the losses by radiation. See table 10. If the difference of temperature between the air and the heated body is great (above $10^{\circ}\text{C}.$), a multiplier must be found from the following formula (s), where R''' is the ratio of the increased loss of heat, and t the temperature difference, in Celsius degrees, between the hot body and the air in contact with it.

$$R''' = \frac{0.552^{1.288}}{t} \quad (s)$$

This ratio, which at a temperature difference of $2^{\circ}\text{C}.$ is 1.11, becomes 1.433 at $42^{\circ}\text{C}.$; 1.684 for $102^{\circ}\text{C}.$; 1.827 for $152^{\circ}\text{C}.$; whilst at a bright white heat the ratio stands at 3.0.

Loss by Conduction.—The third column of Table 9 gives us the value of C , or the conducting power of substances commonly employed in chemical construction. The numbers, taken from the experiments of Peclet, give us the quantity of heat in c.h. units capable of being transmitted, per square foot per hour, by a plate one inch in thickness, the two surfaces differing in temperature by $1^{\circ}\text{C}.$ The heat loss by conduction (C') may be expressed as:—

$$C' = \frac{C \times d}{E} \quad (t)$$

where C = the conducting power of the material, as shown in the Table, d the difference in the temperatures at each side of the plate, and E the thickness of the plate in inches.

It will be as well to close these notes on the emission of heat with a few remarks from Peclet's own treatise, in which he says that all the calculations we have to make relative to the transmission of heat cannot be considered as rigorously exact. But it is not necessary to insist upon rigorously exact formulæ for practical use, where even the slightest movements of the air have great influence upon the quantity of heat carried away, so that in effect, the results of calculation must only be considered as an approximation to guide the engineer.

Let us now see how some of these calculations will work out in practice. On page 28, Vol. I., some particulars are given of the recovery of the waste gases from blast furnaces. In the Gartsherrie works eight furnaces are connected with a 9 ft. cooling tube 300 ft. in length, where the gases are cooled from 260°C. to 200°C. With the downcomers from each furnace, the cooling surface will not fall far short of 8,000 square feet. This surface cools the gases 60°C. They are next passed into an atmospheric condenser consisting of 200 cast-iron tubes, 30 inches in diameter and 40 ft. high, and this is followed by a water condenser 45 ft. \times 18 ft. and 45 ft. high, containing 2,700 malleable iron tubes, each 3 ins. in diameter. The general arrangement of the plant may be seen in Fig. 26.

As each furnace consumes about 500 tons of coal weekly, the downcomers and main tube would have to pass about 4,800,000 cubic feet of gases at 260°C. per hour, or equal to 2,400,000 cubic feet at 15°C. approximately. A cubic foot of blast furnace gas will weigh about 0.078 lbs. at 15°C. , so that the total weight passing would be about 187,200 pounds per hour. These gases have a specific heat of about 0.315, so that on leaving the furnaces they hold

$$187,200 \times 260 \times 0.315 = 15,331,680 \text{ C.H. units.}$$

On reaching the end of the main tube, the temperature of the gases has been reduced to 200°C. , or

$$187,200 \times 200 \times 0.315 = 11,793,600 \text{ C.H. units,}$$

the difference being 3,538,080 C.H. units, or 442 C.H. units per square foot per hour. Let us now see to what figures the formula will bring us:—

If we turn to Table 9, we find that the number for wrought iron is 0.5698 (R) and that in Table 10 the ratio (R'') for high temperature is 2.74 for 215° , which is the temperature difference of the mean temperature of entry and exit; the following calculation will therefore show us the heat lost by radiation per square foot of surface:—

$$0.5698 \times 215 \times 2.74 = 335 \text{ C.H. units.}$$

The loss by contact of air will be: (n)

$$0.427 \times 215 \times 1.03 = 177 \text{ C.H. units,}$$

or in all $335 + 177 = 512$ C.H. units, a result 15 per cent. in excess of the quantity arrived at by the first method. Both processes serve a useful purpose, nevertheless.

We may now refer to the second stage of the process, where the gases are further cooled by an air condenser from 200°C. to 70°C. —a mean of 135°C. , the temperature of the air being 15°C. , and the surface of the condenser measuring 63,000 square feet.

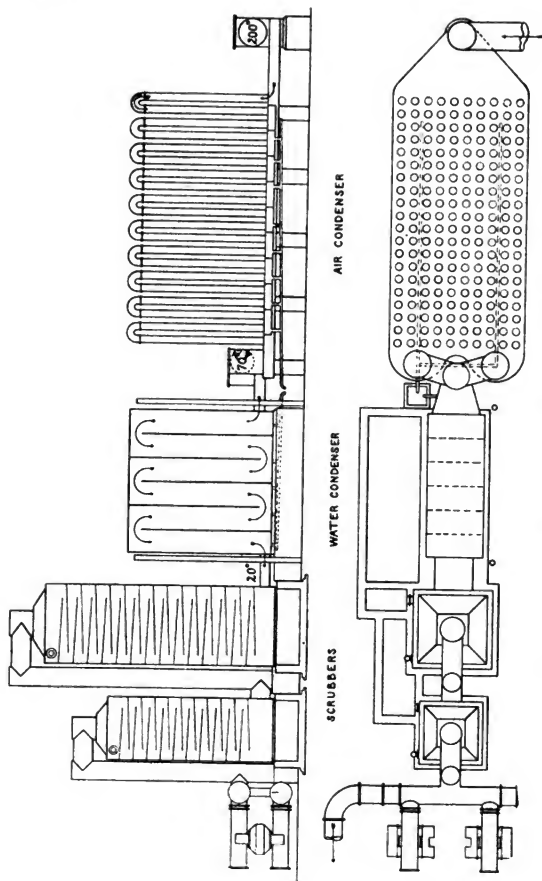


FIG. 26.—THE GARTSCHERRIE BLAST-FURNACE-GAS RECOVERY PLANT.

We have seen that the heat units contained in the gases at the end of the 9 ft. main were 11,793,600, and now that they have been reduced in temperature to 70° C., they will contain

$$187,200 \times 70 \times 0.315 = 4,127,760 \text{ C.H. units,}$$

and the difference between these two quantities shows that about 7,665,840 C.H. units must have been dissipated by the condenser surfaces. This is equivalent to 121 C.H. units per square foot per hour.

By calculation, we find that as cast-iron emits 0.648 C.H. units at 15° C. per square foot per hour for each degree of temperature difference, and 0.648×1.76 for 120° C., therefore

$$0.648 \times 1.76 \times 120 = 136 \text{ units per sq. ft. per hour}$$

should be dissipated by radiation alone; and for the loss by contact with air, according to Tables 10 and 11, we should have:

$$0.4275 \times 1.68 \times 120 = 86 \text{ C.H. units,}$$

or in all, 222 centigrade heat units per square foot of condenser surface.

The foregoing calculation, showing as it does nearly double the heat dissipation that was realised in practice, should not be allowed to discredit the system, as, if care were taken to ascertain all the conditions, theory and practice will come very close to each other. Thus, a large quantity of tar and water are deposited in the condenser, and the latent heat of these vapours has not been reckoned in. About 40 gallons of tar and water is the quantity usually condensed per ton of coal on an average, and for the latent heat of these we may put down 61 C.H. units per square foot per hour, which will bring up the figures to 182, in practice, as against the 222 by calculation. As a matter of fact, a correcting factor should always be applied to cases of this kind where the conditions are somewhat abnormal, and such factors will be best ascertained from practice. In this instance, the interior surface of the condensing pipes would be bathed with fluid or semi-fluid tar, which doubtless affects the emission of heat from the outer surface. Nevertheless, even under these conditions, the radiation and loss by contact of air, taken together, amount to 82 per cent. of that calculated.

We may now pass to the last stage, where the gases leaving the air condenser at 70° C. will travel through the water condenser, which they leave at 20° C., the mean temperature being 45° C. Without undue error it may be assumed that after depositing tar and water they will weigh 180,000 lbs. upon entering the water condenser, and it will be convenient to allow the specific heat to remain the same as before. We have then at entry:

$$180,000 \times 70 \times 0.315 = 3,969,000 \text{ C.H. units,}$$

and when leaving the water condenser:

$$180,000 \times 20 \times 0.315 = 1,134,000 \text{ C.H. units,}$$

so that 2,835,000 C.H. units must have disappeared in the water condenser, with its 94,500 square feet of tube surface, which is 30 C.H. units per square foot per hour. The figures at the author's disposal do not allow the comparison to be carried further; and it must be understood that the foregoing have not been introduced here as specimens of an absolutely

accurate investigation, but rather to show technical workers what a fund of information they have ready to hand, and how the technical student may be useful in his generation by helping to gather in facts of the kind illustrated. Peclet and his confrères would have given up many hours of rest and leisure to have secured the thermal results of the large scale workings now so common, but which were scarcely known in their days.

Similar calculations to the foregoing may be made upon the loss of heat from steam pipes and other heated surfaces, and the results will at times be found astonishing, and further, if sufficient confidence be not

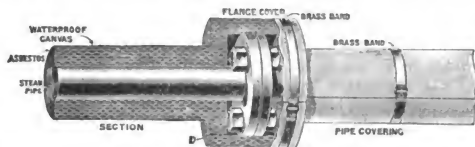


FIG. 27.—VICEROY CELLULAR COVERING FOR HOT PIPES.
(United Asbestos Co., Ltd.)

placed in figures, the radiometer described on page 244, Vol. I. may be employed to give a practical lesson in heat losses. The results, however they may be obtained, will show how important it is to clothe hot surfaces with non-conducting material when the temperature is to be preserved. There are many of these materials in the market, which no doubt the users will search out for themselves, and therefore only one variety, which appears to possess especial merit, need be mentioned here, viz., the productions of the United Asbestos Co., Ltd., of Billiter-street, London, which are shown in the four accompanying illustrations.

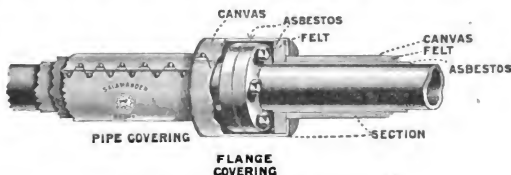


FIG. 28.—SALAMANDER PIPE COVERING.

Many steam users consider it inexpedient to cover the flanges of steam pipes. This is probably owing to the difficulty, when the flanges are covered, in reaching the bolts, should they require attention through leakage at the joints; but when a pipe range is well laid, with thin joints and a sufficiency of expansion pieces introduced, it should but rarely require attention, though, unfortunately, this is the exception rather than the rule.

Fig. 27 shows an asbestos cellular covering for steam pipes and flange covers of the same material, which when fitted to the pipes are covered

with waterproof canvas and bound with a brass band. It is exceedingly light and durable, and gives a neat appearance to the installation. In sheets 3 ft. square, the foregoing covering, one inch in thickness, costs about 1s. 4d. per sq. ft., while the removable covers for pipes will cost 2s. 7d. per lineal foot for pipes $5\frac{1}{2}$ ins. in outside diameter.

Another variety of covering is shown in Fig. 28, and is easily and quickly applied, removed or replaced, and there is no danger of its falling off through vibration or exposure. It consists of hair felt protected by asbestos mill-board, which is placed next to the pipes, whilst the outer covering is of oiled canvas, which may be painted and so rendered further waterproof. Flange coverings are also made for this type of material.

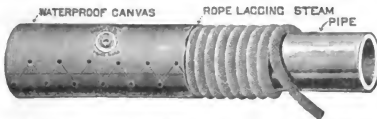


FIG. 29.—SALAMANDER ROPE LAGGING FOR PIPES

A form of non-conducting covering, easily and quickly applied and very efficient, is the rope lagging shown by Fig. 29. It is particularly useful for application in confined places, and also for all temporary work, as it may be instantly removed and used again on pipes of any diameter. Such lagging, one inch in diameter, costs about 25s. per one-hundred lineal feet, but there is a second quality made at about one-half this price.

Cold pipes connected with refrigerating machinery require covering just as much as steam pipes containing a hot medium, and it is not an unusual thing to see an inch or two of frost on these pipes in an uncovered

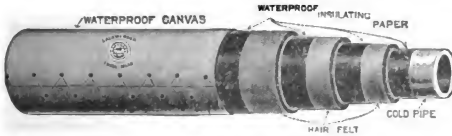


FIG. 30.—SALAMANDER COLD-PIPE COVERING.
(United Asbestos Co., Ltd.)

installation. A covering for such work, found to be suitable in practice, is a combination of hair felt and specially prepared waterproof paper and canvas, built up in alternate layers as shown in Fig. 30, the whole being encased in laced canvas, or if preferred, in canvas braced with brass or steel bands. Large vessels, boilers, tanks, etc., may easily be covered with any of the foregoing materials, and in most cases the economy of heat is more than sufficient to pay a handsome interest on the outlay. When a pound of water is condensed from each square foot of steam pipe per hour, it does not require much calculation to prove the economy of non-conducting materials, and there are many such cases.

We may now turn to some practical applications of the principles that have been set out in the foregoing pages, commencing first with the ordinary steam-boiler, some details of which are shown in Fig. 31. The fire, as is well known, burns in the circular tubes, which are consequently called the furnace tubes, and the products of combustion pass along these tubes, drop down into a flue running underneath the bottom of the boiler as shown, and then, having arrived at the front end, they rise into the side-flues, one on each side of the boiler, and pass away into the exit flue. The distribution of the heat has been gone into very minutely upon page 263, Vol. I, so that it is not necessary to go over that ground again except to point out that the temperature of the waste gases leaving the boilers was 399°C. , and leaving the economisers 161°C. , while 671 C.H. units of heat, only, were passing away in the chimney gases for every 6,730 units

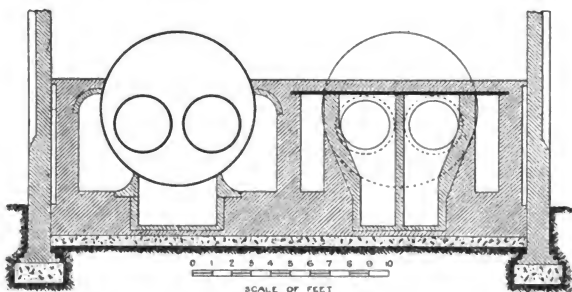


FIG. 31.—THE SETTING OF A LANCASHIRE STEAM-BOILER.

sent in at the furnace end. The heat necessary to cause the draught is then but one-tenth of that yielded by the fuel, and this will be found an important factor in determining the economy of mechanical draught.

There are a few points in boiler setting that require attention, one of which is the necessity of ample room in the side flues. Flue-cleaning is not a pleasant occupation even under the best conditions, but it might, perhaps, be made more salubrious if those who designed the settings were made to clean the flues. Another point worth considering is the advisability of providing doors in the brickwork at the boiler front to allow of access to the flues for cleaning—and at the chimney end also. In most boiler settings the brickwork has to be knocked down for flue cleaning and built up again before starting off, when all that need be done is the opening and closing of a door. Great care should be taken in building the flues at the chimney end of the boiler. If the temperature of the gases entering the chimney is found to be unusually high, the division walls between the flues should be well examined, as it not infrequently happens

that a large leakage of hot gas takes place from the end of the circular flues where the temperature may be 700°C . direct to the chimney, without passing through either the bottom flue or the side flues.

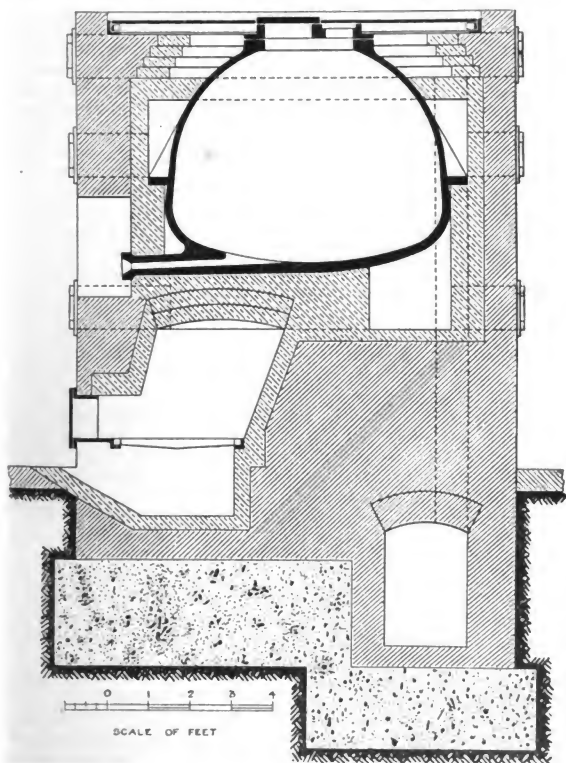


FIG. 32.—SECTION OF NITRIC ACID RETORT SETTING.

The settings for other boilers scarcely require any description. The mode of setting the Babcock and Willcox boiler may be seen on page 254, Vol. I., the tubes containing the water being bathed in flame for a very considerable portion of their area. In this way the furnace acts as a loco.

furnace with an extended fire box, the remarks upon which on page 252, Vol. I., may be referred to again.

It is difficult to attempt any systematic classification of the apparatus used for the application of heat to chemical or mineral substances, but there may be found a method of grouping such appliances as will enable points of similarity or difference to be readily distinguished, and will serve to show the evolution of ideas, and the means that have been taken for their practical accomplishment. If we take the setting of the Lancashire steam boiler as a type of construction, we should not hesitate to place the setting of a nitric acid retort in the same class, and though the details differ in each case, this results more from the nature of the materials operated upon than from any other consideration. Fig. 32 shows the most modern setting of a nitric acid retort, which enables the fused nitre cake to be run off without danger and without causing delay. It has been found by experience that if the whole of the retort is kept hot (above the temperature of condensation of the liquid acid) the retort has a very long life, but if liquid acid is allowed to condense upon any part of it, that portion is quickly destroyed. Naturally, the top of the retort is the portion particularly exposed to such influences, but by taking the flues over the top of it, as shown in the illustration, no opportunity is given the acid of condensing there. The fire-place is comparatively small; nitric acid does not require a high temperature for its expulsion, and the lower the temperature at which it can be distilled over, the better will the product be. As a matter of fact, even under the ordinary atmospheric pressure, nitric acid may be distilled over at such a temperature that the bulk of the water, over and above that necessary to form the mono-hydrate (HNO_3), may be left behind in the fused nitre-cake. Nitric acid is also made from cylinders set horizontally with large fire-places directly underneath them, but there is no advantage now in this somewhat antiquated system, which is rapidly being relegated to the limbo of forgotten things.

Of all subjects, perhaps, destructive distillation furnishes us with as good a series of examples as any other operation in the whole range of manufacturing chemistry, commencing at one end with the coal-gas retort and the beehive oven for coke, and finishing with the Young and Fyfe shale retort and the Semet-Solvay coke oven. If we examine the process of destructive distillation, we shall find that the main product sought may be either the solid portion which is left behind in the retort, or the gaseous portion that is driven off by the action of the heat, and, according as to whether the first or the second object is to be attained, so must the plant be designed and installed. In the old fashioned beehive oven, the coke was the article worked for, the gaseous products being allowed to escape into the atmosphere, often only partly burned, to the great annoyance of the residents near. In the year 1880 or just before, attempts were made upon the large scale to collect and render merchantable the gaseous emanations from the coking of coal, which, though not immediately successful, led up to the improved plant we find working

to-day. It was then found that the products recovered from beehive ovens were of a different chemical character to those obtained from gas retorts, and this discovery at once threw invention upon another track, produced the closed coke oven, and sealed the doom of the existing open oven, wherein all the gaseous products were wasted. In the old type of oven the early hours of the distillation of a fresh charge were rendered effective by the heat left by the previous charge, as at this stage the temperature of the gases was not high enough to admit of their combustion, and this went on until the gases were hot enough to burn, when, of course, the interior of the oven and its contents became quickly heated again, and the heat that was removed by the gasification of the coal was once more replenished and awaited the next charge. There were no flues in connection with these ovens, except in some instances where the low level smoke caused a nuisance; but some beehive ovens were put up several years ago at a Yorkshire colliery in which the waste heat was utilised

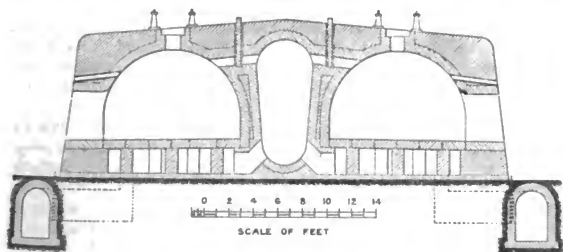


FIG. 33.—IMPROVED BEE-HIVE COKE OVENS.

more thoroughly than in those of older pattern. Fig. 33 shows a section of these ovens, from which one may readily understand how they are operated.

The ovens were originally designed as by-product-recovery ovens, with a view to producing a better looking coke than can be made in the ordinary closed oven, but as the coke producing plant was finished long before the recovery plant had reached that stage, the ovens were worked by allowing the gaseous products to escape into the flues and to burn there, thus keeping the ovens constantly at a high temperature, much higher in fact than the quality of the fire-bricks warranted, as the surfaces of the bricks in the central oval flue were always in a state of semifusion. The principle upon which these ovens were constructed, was that only the portion of gas containing valuable hydrocarbons would be collected, the remainder being allowed to burn in the central flue and find its way under the floor of the oven into the front flue leading to the chimney. As recovery ovens the principle was never demonstrated, as the brick-

work had been so punished by the high temperatures in the flues and the introduction of wet smudge on to the highly heated floor, that by the time the recovery plant was completed the leakage of air completely burned up the volatile products when the exhauster was put on. As coke ovens, the owners expressed the opinion that so long as the quantity and quality of the coke kept up there was no need to trouble themselves about the by-products.

Ovens of the Otto and Semet-Solvay type, yielding as they do a by-product akin to gas-tar, have been introduced into practice at a rapid rate, and ovens of this type have all but driven out the old beehive pattern, except from those establishments who still trade upon the reputation of their ancestors. During the last two decades various forms of coke ovens have been tried and abandoned, patent after patent has been obtained, but as a final result of scientific research, combined with not a little "trial and error," the modern coke oven must be styled the "Semet-Solvay." The waste of coal in the old beehive oven was enormous. The ovens of the Semet-Solvay type will produce from 12 per cent. to 15 per cent. more coke from the same fuel than the best beehive ovens in existence, and in these latter, the products of distillation are not only burned and destroyed, but the heat of their combustion is lost also, amounting, in many instances, to at least two-thirds of the total heat of combustion of the coal. It is well for us that this waste has not been allowed to continue.

The construction of the Semet-Solvay oven may be seen from the cross sections shown in Fig. 34, which indicates two contiguous ovens, the one cut through a hot-air flue while the other is taken through the charging hole, or gas outlet. The ovens vary in width to suit the quality and characteristics of the coals under treatment. Rich coals usually require a wider oven than the leaner kinds, but 16 inches to 18 inches is a common width for an oven, and with a length of 33 feet, and a height of 6 feet, make a chamber capable of producing about 3.75 tons of coke every 24 hours. Hollow flues run through the walls of the oven, as shown in the illustration, being formed of hollow bricks. In these flues the gas, from which all condensable products have been removed, burns with the necessary air, and the products of combustion pass along from the top flue into the next lower, and so on, until they join in the gas flue under the oven, finally passing away into the main chimney flue. In this way the walls of the ovens are heated on both sides, and so transmit their heat to the oven chamber.

The design of a coke-oven is of the greatest importance, as the oven must be kept at a uniform temperature throughout. The heat should be quickly transmitted from the heating flues to the fuel, and provision for rapid and thorough repairs must be made to ensure the installation being successful. These points have been most carefully studied in the "Semet-Solvay" ovens. The horizontal flues allow of free inspection and regulation of gas and air, the former of which is admitted at various points, so as to secure a regular temperature. The channel flues, with their thin sides, rapidly transmit the heat, and as they have only to support their

own weight, they do not quickly deteriorate. As will be seen from the illustration, the top structure of the oven is carried by an independent arch on solid supporting walls between two ovens, and so the flues or lining can be readily removed and repaired without occasioning any disturbance to any other brickwork, and in practice it has been found that any oven can be repaired while the adjoining ovens are at work.

As to cost, four beehive ovens will cost about £320, and will make about the same weight of coke as one "Semet-Solvay" oven, which costs, however, not less than £750, with its full proportion of by-product plant.

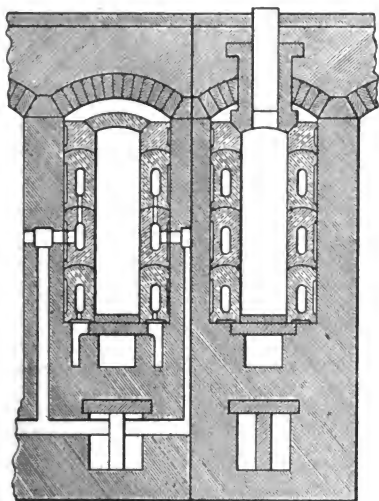


FIG. 34. — "SEMET-SOLVAY" COKE OVENS.
(Cross Section.)

From a unit of fuel, the beehive will produce a revenue of £55, while the "Semet-Solvay" yields no less than £87. A series of 50 old pattern beehive ovens erected on Furnace Hill, at Chapeltown, for Messrs. Newton. Chambers & Co., cost £4,000, and when at full work produced 400 tons of coke per week, burning up all the by-products.

Most coal undergoes contraction when submitted to destructive distillation, and so leaves the walls of the oven on the top and sides, which renders its removal easy. After many attempts and failures to remove the coke from the oven *en bloc*, it was found possible to push it out by means

of a hydraulic ram, or, in some cases, by means of a steam ram. This is now the common method of discharging the ovens.

But perhaps a better illustration of the progress made in apparatus for destructive distillation is that afforded by the shale retort. This subject has been dilated upon by Mr. George Beilby, who is the author of many improvements, and the history of shale retorting as given in the introductory chapter to Vol. I. will also be found interesting, as illustrating the fact that science can be made to dovetail in with practice when the rule of thumb element is kept out of the way. The latest shale retort, which is the embodiment of many years' practical experience, is shown in Fig. 35 as the invention of Messrs. Young and Fyfe.

The Young and Fyfe retorts were devised as far as possible to convert the fixed carbon of the shale residues, more or less, into fuel gases with an increased yield of ammonia, and to do so without employing such a heat as would lead to the fluxing of the residues in the retort. There were other considerations to which attention was directed, the principal of which was to reduce the manual labour as far as possible by doing the work by gravitation. It was also necessary in any improved system to, as far as possible, utilise the heat of the combustible gases, used to effect the distillation of the shale. In most of the older systems the shale residues are discharged from the retorts, containing about 50 lbs. of carbon per ton, that can be utilised. In many cases, owing to the small area of the retorts in relation to the outside walls, or the rate at which the shale is distilled in relation to the outside walls, and to the high temperature at which the products of combustion are allowed to escape into the air, from 40 per cent. to 70 per cent. of the total heat of combustion of the gases burned in the flues around the retorts is lost or wasted. In the retort shown by Fig. 35, the lower end is provided with a large combustion chamber corresponding in position to the lower hopper in the mechanical discharging retorts. The bottom of this chamber inclines to the discharge door in front at such an angle that while not sufficiently steep as to allow of the residues sliding out by gravitation alone, requires a little manual assistance to cause it to do so, and to prevent the shale dropping faster down the front side than down the back, a plate is inserted, inclining to the back, which equalises the fall of the column of shale. The shale residues drop out of the brick portion of the retorts into these chambers, in a red-hot state, but instead of being allowed to cool at once, they are kept for a time in a state of ignition by the admission of a supply of a carefully adjusted mixture of air and steam, which burns the carbon remaining in the residues, producing an increased yield of heat and heating gases and additional ammonia. The gases resulting from the combustion of the carbon in the residues, together with the undecomposed steam, pass from these chambers up through the shale residues and shale contained in the externally heated brick and iron portions of the retorts and in the hoppers, performing in their course the same functions as they did in the original Young and Beilby retorts. By thus burning the residual carbon in these combustion chambers, which are not heated externally, the fluxing of the residues is

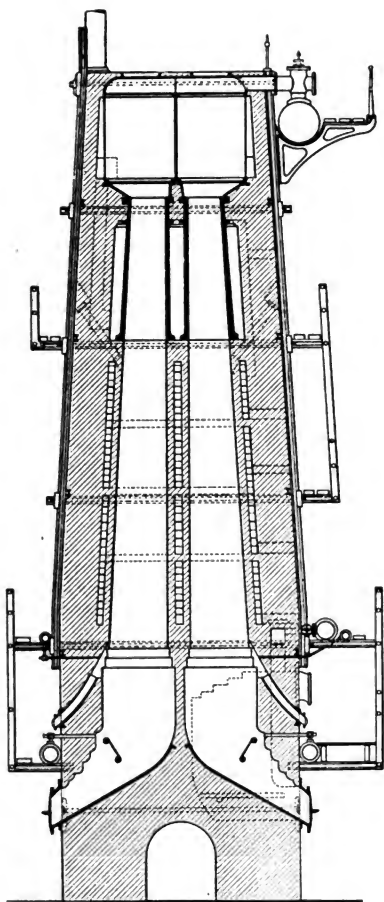


FIG. 35.—MESSRS. YOUNG & FYFE'S SHALE RETORT.

reduced to a minimum, and the heat upon the externally fired retorts does not require to be so high, thus saving tear and wear to a very considerable extent.

The use of the air effects a further economy, inasmuch as it acts very much as an equivalent of steam. The quantity of air is considerable, amounting to from 3,000 cubic feet to 4,000 cubic feet per ton of shale, and has been found equivalent in its action to the steam from about 30 gallons of water. Moreover, the air on its way to the retorts is made to pass over the surface of the hot spent ammoniacal liquor flowing from the ammonia still, and in this way takes up steam equal to about nine gallons of water, thus saving the boiler power and the cost for coal and labour to raise that quantity of water to steam per ton of shale distilled.

In the design shown in Fig. 35, the rectangular form of retort is retained, as it is stronger and less costly to construct, and, what is still more important, it gives the largest possible area of retorting surface, in relation to the surface of the enclosing walls of the bench.

The coal gas producers, which are only required to heat up the retorts at starting, are placed in the basement of the division wall, instead of between each four retorts as in the old system, and this arrangement still further increases the space available for retorting surface in proportion to the area of the enclosing walls. To enable the heat in the products of combustion to be utilised as fully as possible, and to prevent the oil which is partially condensed upon the surface of the cold shale from finding its way down into the upper ends of the retorts and there being re-volatilised, the hoppers are made of considerably greater depth than in the Young and Beilby system, and are constructed so as to present a large heating surface. The hoppers are further surrounded by flues enclosed in brick walls. The hot products of combustion from the flue surrounding the iron retorts, which in other arrangements are allowed to escape into the air at a temperature of from $330^{\circ}\text{C}.$ to $440^{\circ}\text{C}.$ are carried up into the flue surrounding the hoppers, and there a part of the heat remaining in the products of combustion is thus utilised in heating the shale and re-volatilising the condensed oil from the surface shale preparatory to its dropping into the iron retorts, the products escaping into the air at a temperature rarely exceeding $170^{\circ}\text{C}.$ Young's Paraffin Company have now erected three benches of 80 retorts of the improved design, one at each of their works, Addiewell, Uphall and Hopetoun, and are at present engaged in erecting a fourth, at their Addiewell Works.

The cost of erection is considerably less than that for mechanical discharging retorts, but the labour required is more, although considerably less than that required for the old Young and Beilby system. The cost for charging the shale, discharging the spent shale residues, and attending to the regulating of the heats, and the whole labour directly required for the retorting of the shale, comes to less than threepence per ton of shale distilled. The extra cost for labour is to a large extent compensated by the much less first cost of erection, and by the lessened tear and wear due to the freedom of all moving parts, and the very much lower

temperature at which the retorts require to be worked, and consequent comparative freedom from clinkering of the shale residues.

In every other respect the results are largely in favour of the retorts worked by gravitation, assisted by manual labour alone. The new benches of retorts are erected upon the foundations of the worn-out Young and Beilby benches, which distilled 120 tons of shale per day. The new benches distil 280 tons on the same area in the same time. This great increase in the quantity of shale treated on the limited area saves an enormous amount of heat, due to the comparatively limited area of the external walls allowing less heat to escape through them, and the products of combustion leaving the bench at 170° C. instead of 450° C. or so, effects a still further economy of fuel. The combustible gases are in that manner more economically used, and the third supplementary process of incinerating the carbon left in the shale residues by the mixture of steam and air in the large combustion chamber at the bottom of the retorts produces heat and combustible gases that would otherwise be lost, and there is a large excess of combustible gases over that necessary to distil and treat the shale. At the Uphall Works this excess of combustible gas has been applied to, and found sufficient to fire, an old Young and Beilby bench still at work, which previously required from five to six tons of coal per day. The shale from which this large excess volume of gas is obtained is one of the poorest mined by Young's Company, yielding only from 22 to 23 gallons of oil per ton, and the gases have been scrubbed with oil so as to yield from $1\frac{1}{2}$ to 2 gallons of naphtha per ton of shale prior to being used in the retorts. The use of the carefully adjusted mixture of steam and air in the shale distilling process saves steam, as already stated, equivalent to about 30 gallons of water per ton of shale, and the smaller quantity and more concentrated ammonia liquor resulting from this less use of steam saves plant and fuel in the subsequent treatment for the manufacture of sulphate of ammonia.

The yields of crude oil and sulphate of ammonia per ton of shale are quite equal to those from the mechanical discharging retorts; and the oil, owing to its partial condensation, filtration, and redistillation from the shale in the hopper, is of very superior quality, and yields a higher percentage of refined products than is the case when the oil vapours are drawn away from the upper ends of the retorts, *i.e.*, at the bottom ends of the hoppers.

There is no claim for individual novelty in the various parts of these new retorting arrangements in Young's Paraffin Company's Works. They are a collection and combination of the parts of previously existing systems of retorting shale which experience has shown to yield the most economical results, and also the elimination of parts which have been tried and failed from defective construction. The novelty consists in the collective arrangement and combination of apparatus to successfully carry into effect those economical features of the retorting systems, and to carry out economies where others had failed.

It is somewhat difficult to assess the actual gains of this system of retorting over those previously existing. The first cost of erection must

be considerably less per ton of shale distilled. The smaller depreciation, together with the interest upon that prime cost, will almost equal the saving in cost of labour. The statements made regarding the saving from mechanical action retorts have been very misleading in consequence of economies concurrently introduced into the shale breaking and other departments having been all credited to the improved mechanical discharging retorts, which were equally applicable to other forms. The whole

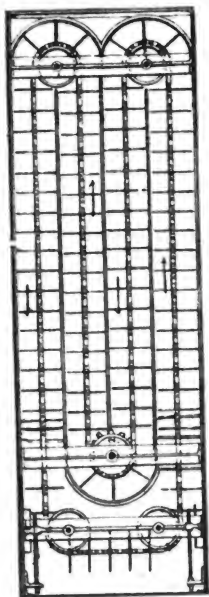
cost for labour attending to the actual working of the manual gravitation retorts being, as already stated, under threepence per ton of shale, the substitution of mechanical for manual action could only save a part of that sum.

The much smaller area of the walls of the bench in relation to the retorting surface, and the greater use made of the heat of the products of combustion before allowing them to escape into the air, effect a saving in cost of fuel much greater than the whole cost for labour, and the successful use of the steam and air effects an equal amount of economy in fuel besides the saving in boiler power, and other plant.

These retorts work quite as smoothly, and even more reliably, than do the mechanically discharging retorts, the shale residues being discharged under the sight of the retort men, and only withdrawn when thoroughly exhausted. There has been comparatively little trouble from the clinkering of the shale residues, any clinkering that has accrued being confined to the combustion chamber at the bottom of the retorts. There has been no trouble from the shale residues clinkering in the retort walls, as is still the case in mechanical discharging retorts worked at high temperature.

FIG. 36.—THE
"BOWERS" CONTINUOUS RETORT
FOR WOOD DISTILLATION (Plan)

not many years since wide cast-iron cylinders were almost exclusively employed for the distillation of wood, and as these retorts were not suitable for the distillation of sawdust, it was by general consent concluded that sawdust distillation was impracticable. It is true, however, that in some few cases mechanical retorts were employed for this purpose, but the users never seemed happy when working with them.



The mechanical retorts found illustrated in several treatises on technology, and in the records of the Patent Office, may in most cases be passed over without notice. Faulty designs, incorrect methods of construction, ignorance of expansion and contraction and other physical laws, combined in a great measure to cast ridicule upon the mechanical retort for utilising sawdust, until the appearance of the "Bowers" continuous retort, a plan and section of which may be seen in Figs. 36 and 37.

This retort is really a shallow closed iron box, within which an endless chain conveyor carries the sawdust or other similar material up and down a series of channels, the wood entering at one end of the retort, the charred material leaving it at the other end, away from the fireplaces. The chain conveyor works over horizontal pulleys or sprocket wheels, as shown in Fig. 36, and is driven at such a speed that the sawdust is completely carbonised by the time it reaches the outlet. Means are provided for tightening the chain, if necessary, without any suspension of operations being involved. The heating of the retort is effected by two fireplaces situated under the cast-iron floor of the chamber, and the products of combustion travel through four flues on their way to the chimney, as shown in Fig. 37, special means being taken to ensure as far as possible a thorough and equal distribution of the heat.

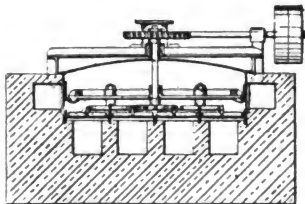


FIG. 37.—THE "BOWERS" RETORT.
(Cross Section.)

Not only has this retort made the carbonisation of sawdust a profitable operation, but it has enabled other waste woods to be utilised, such as spent dye-woods and the turnings from wooden bobbins, which are produced in this country in immense quantities. This retort has also the advantage that the heat applied to the material treated within it can be modified to almost any degree within reasonable limits, so that it may either be used as a simple drier or as a carboniser. In fact, it is so employed in the carbonisation of spent dye-wood, which contains in its natural state a very large percentage of water. In carbonising this material two retorts are required, the first a low temperature chamber, wherein the moisture is simply expelled, and from this it is delivered into the high temperature retort, where carbonisation takes place. One retort as illustrated will carbonise 40 tons of sawdust per week with an expenditure of 7 tons of coal for fuel. Fifty tons of dry hardwood turnings could be put through such a retort weekly, yielding, besides 13 tons of charcoal, about three tons of grey acetate of lime and one hundred gallons of rectified naphtha of 60%.

The Bowers retort may also be used as a drier. It has been employed as such for the treatment of sewage sludge, containing 60% of water, as it comes from the filter press. In some experiments communicated to the

author, the machine dried half a ton of wet sludge per hour, evaporating six pounds of water per pound of slack fuel.

It may be deemed an omission were the subject of destructive distillation passed over without some mention of the ordinary coal-gas retort, especially as coal distillation, or, as it is called, "carbonisation," has been practised for some years, solely for the coke and the distillation products, the gas being considered the waste product. There is, however, no likelihood of any extension of this industry until the price of benzol (of which about three gallons are recoverable from the gas from one ton of coal) has again reached half-a-crown per gallon—which is not very probable, and as the making of animal charcoal from bones is about the only process in which gas-retorts are employed for purely chemical purposes, it will be sufficient to call attention to King's Treatise on the Manufacture of Coal Gas, by Mr. Thomas Newbiggin.*

We may now leave the subject of destructive distillation, and turn to those processes in which materials require to be heated while undergoing some transformation of a different character to that just discussed. These operations in former days were entirely effected in furnaces worked by hand, but the desire to avoid manual labour as far as possible has evolved a host of mechanical furnaces always designed to secure some special object being attained. Amongst the hand furnaces for chemical operations, we find the black-ash furnace shown by Figs. 3 and 25, but though this type is still employed for sundry operations it is nearly extinct for the purpose for which it was originally designed. In close relationship with the black-ash furnace stands the copper-refining furnace, and the smelting furnaces generally, usually styled reverberatory furnaces, and these vary in their details according to the work that is expected from them. A modern copper-refining furnace is shown in Fig. 38, which represents a type recommended by the Allis-Chalmers Co., of Chicago, and of which Mr. H. L. Bridgman is the designer.

These furnaces are styled "open" furnaces, as the materials treated in them are exposed to contact with the flame or products of combustion, which, of course, is necessary when intense heating is desired, but when contact with the flame or the products of combustion would be injurious, or when the products evolved from the materials require to be collected, it is usual to employ what are called "close" or "muffle" furnaces. There are exceptions, of course, to any general classification of this kind, which may be illustrated as follows:—The salt-cake furnace now universally employed is shown by Fig. 4; it is a close or muffle furnace, the mixture of sodium bisulphate and salt lying within the muffle, while the products of combustion play around it. Hydrochloric acid gas is liberated from the mixture, and is passed into a water "condenser," where the gas is readily absorbed. In days gone by, this operation was effected in an open furnace of the type of Fig. 3, the products of combustion mixing with the hydrochloric acid gas, which often left the furnace at temperatures exceeding 600° C. The difficulties of condensation, together with the

* London: William B. King, 1878.

necessity of employing coke as fuel, brought about the introduction of the muffle furnace, and the processes have been thus so improved that no one has any desire to revert to the original but simpler mode of construction. Again, when the operation was one of oxidation, such as the calcination

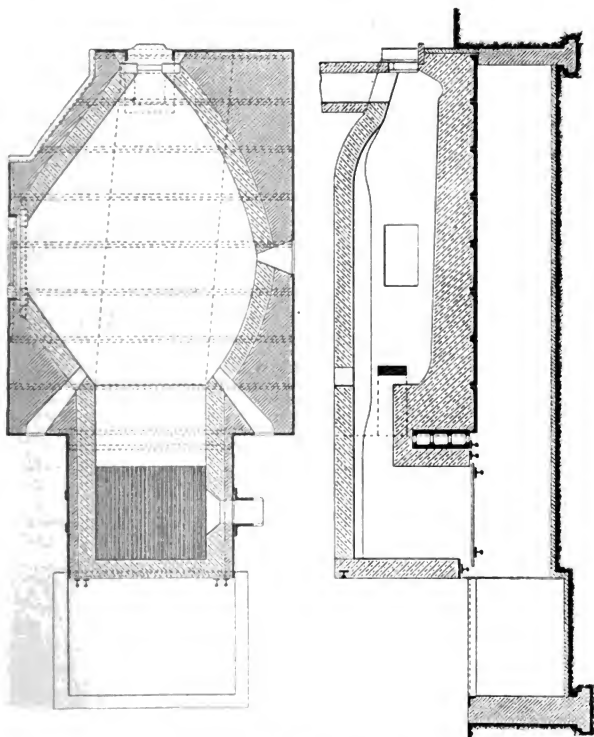


FIG. 38.—COPPER REFINING FURNACE.

of burned copper pyrites with common salt, the furnace employed was originally the open type, sometimes heated by means of producer-gas. In these days, the calcination is effected in close or muffle furnaces, of which Fig. 39 shows the form of construction.

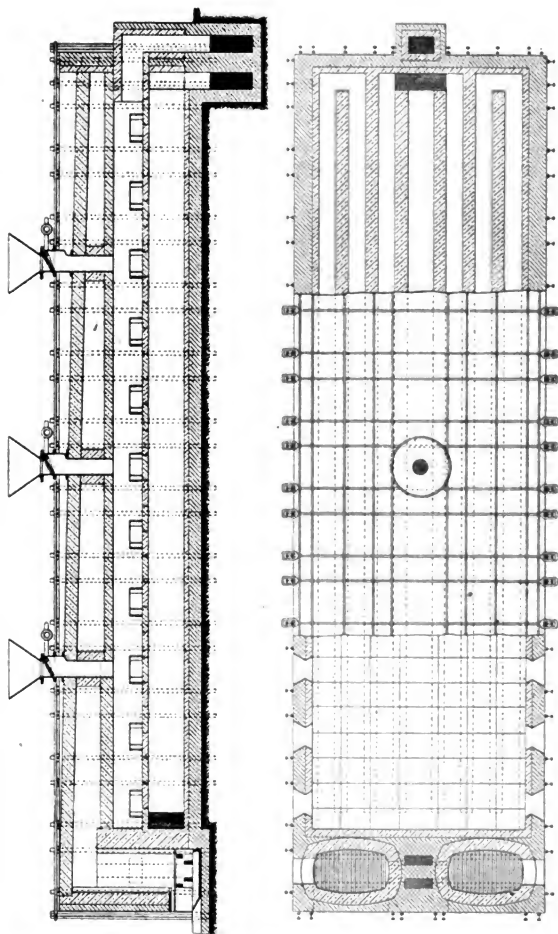


FIG. 39.—MODERN COPPER PYRITES CALCINER

These furnaces are now built of much greater length than formerly. This conduces very largely to economy of fuel, and it is generally found that the ore is better roasted in long furnaces than in those of shorter dimensions. Short furnaces are great fuel wasters, owing to the non-conducting character of the materials of which they are built. When an open calciner is employed to roast such minerals as mixtures of galena and pyritic ores for smelting, there is no need for such a perfect calcination as is required when fine pyritic concentrates are undergoing treatment for chlorination. In the former case, from 3.0 per cent. to 5.0 per cent. of sulphur is usually left in the roasted ore, the surface exposed to the roasting influence being about 90 square feet to the ton of ore calcined per 24 hours, while in the latter case wherein 0.5 per cent. of sulphur is permitted to remain the area exposed must be reckoned as 170 square feet per ton of ore per 24 hours.

Let us now turn to another operation, which not only serves to illustrate a different type of furnace, but also teaches several important lessons. It is the operation of burning copper pyrites, and other metallic sulphides, having in view the utilisation of the evolved sulphurous acid. The pyrites kiln, like all other pieces of chemical plant, has undergone a steady evolution. It is just about 30 years ago since the author was called in to advise in the better manufacture of vitriol in a works of the old pattern, and he found in use a kiln for burning coal brasses (iron pyrites from the coal measures), *with a coal fire underneath to make them burn*. The modern vitriol maker may smile at this, but let him remember that perfection does not come at once. A section through the best form of pyrites burner is shown in Fig. 40. It will be seen to possess a cast-iron casing, usually called burner fronts, which add very materially to the life of the kilns. Some kilns are constructed without these fronts, but unless the gases are required at a very high temperature this method of construction is not advisable, as the retention of heat in the kiln is fatal to those varieties of pyrites which show a tendency to flux, and especially so to those of a "cracking" or what is termed "explosive" kind, the disintegration of which is due to the unequal expansion on rapid heating. Moreover, a thick bed of ore in the kiln is not admissible in such cases, as the interstices between the lumps would be quickly choked by the dust, and by the small flakes split off from the larger particles.

In burning pyrites the combustibles are sulphur and iron (FeS_2) and there is the heat of formation of the FeS_2 to undo. In ordinary pyrites kilns the thickness of the bed of material over the bars is about 20 inches, but this must be varied according to the grade of ore used. Some experiences of the author, with reference to the burning of Aguas Tenidas pyrites, may be found interesting. This pyrites (now no longer on the market owing to the mine being flooded) was a non-cupreous, non-arsenical Spanish pyrites containing traces of nickel and cobalt and more than 50% of sulphur. When the sulphur was burned below one per centum the cinders were valuable as an iron ore for the blast furnace, but if they contained more than one per cent. they were unmerchantable. A works using this pyrites had a number of kilns, the grate area of each of which measured 8.0 square feet. These formerly burned seven cwts. of Welsh pyrites per 24 hours, and when

the Aguas Tenidas was substituted for the Welsh ore the same complement was sent to each kiln. Under the altered conditions, the Aguas Tenidas cinders contained from two per cent. to three per cent. of sulphur and thus were valueless. The quantity charged was then gradually reduced until the cinders contained less than one per centum of sulphur—this happened with a charge of four cwts. per kiln per 24 hours, which is equal to 2·3 lbs. per square foot of grate area per hour. The grate surface of each kiln was now enlarged to the utmost limit the existing walls allowed of, and the area then measured 14 square feet. They were then charged with four cwts. per 24 hours, and the weight of the charge gradually increased until the

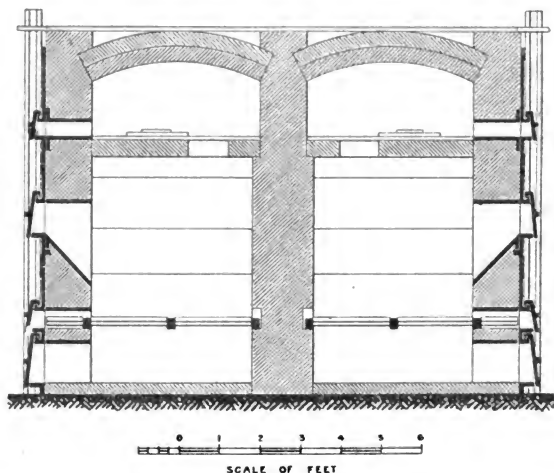


FIG 40.—PYRITES BURNERS (Cross Section).

sulphur in the cinders reached an average of 1·2 per cent. This happened at 7·5 cwts., and when the charges were made a constant quantity of seven cwts., the cinders never contained more sulphur than one per centum. A simple calculation will show that this last figure works out to 2·3 lbs. per square foot per hour also.

The regulation of the air to both pyrites and brimstone kilns is a matter of the utmost importance, and the appliances having this object in view should be well under control. The doors enclosing the ashpit, those enclosing the ends of the fire-bars, and the charging door, should be planed true, so as to be absolutely air-tight. The door for air admission below the bars may be of very small dimensions, say four inches by three inches, furnished

with an easily regulated slide. The aperture in the charging door is not usually employed for air admission; it is really a sight hole, and may be made one-and-a-half inches in diameter. In connection with the draught of kilns, it may be mentioned that the top arch is generally set too low, as a shallow flue causes too much friction with the passage of the 70 cubic feet of air that is necessary for the combustion of one pound of iron pyrites in some works, or the 90 cubic feet per pound used in others. The pyrites burner illustrated in Fig. 40 may be employed for large copper pyrites or large iron pyrites of most varieties, but it is not wise to allow pieces that will go through a three-sixteenth inch screen to enter them. It is true that in some works all the smalls produced during the breaking of the pyrites is charged into the large ore kilns without detriment to the proper combustion, but the author also knows of many works where this plan has been tried and abandoned.

For the combustion of small pyrites—that is, the portion passing through a three-sixteenth inch screen—a burner of special pattern is provided. There have been and perhaps are still in existence many different kinds of smalls burner, but the simplest, cheapest to build, and most efficient of all the hand furnaces is that shown in Fig. 41.

It is not necessary to describe or illustrate any other form of this burner, as the principle upon which the operation depends is clearly shown by the figure. A series of shelves placed one above the other is charged with the small pyrites, the charging always taking place through the hopper upon the top of the burner. Previous to charging, the material on the lowest shelf is pushed off into the burned ore den below it, and the material upon the upper shelves is pushed down from shelf to shelf until the top shelf is left vacant, and therefore ready to receive the new charge. As the combustion is most intense upon the second shelf, and as the products of combustion from all the shelves pass over the top shelf upon which the cold green ore is first charged, there is sufficient heat to start the combustion well upon its way, and the radiation of heat from shelf to shelf serves to prolong the period of high temperature, and the air entering the lowest shelf or the burned ore den forms a heat exchanger of such excellence that the temperature of the burned ore when taken away from the kiln seldom exceeds 40° C. And then again the air entering the den with its normal proportion of oxygen passes from shelf to shelf losing oxygen, but gaining sulphur dioxide on its way, so that by the time it has left the top shelf it is almost as rich in sulphur dioxide as the gases from an ordinary large ore pyrites burner. In order that the combustion may go on to completion the material lying upon the shelves must be occasionally stirred or raked over with a tooth-rake, otherwise the surface cakes over and energetic oxidation stops. This manual labour is one of the drawbacks to this type of furnace, but where labour is both cheap and plentiful there is some compensation in the lower price of small pyrites.

In some works using smalls burners, the raking of the shelves is performed by the workmen from a movable platform, which may be raised higher or lower to suit the exigencies of the situation, but in other estab-

lishments the floor at the front of the kiln is placed at a different level to that at the back, and so the workman is able to execute his work more comfortably. Two burners similar to those illustrated by Fig. 41 will burn satisfactorily 10 to 12 tons of small pyrites weekly, reducing the sulphur contents of non-cupreous pyrites to less than one per cent. This

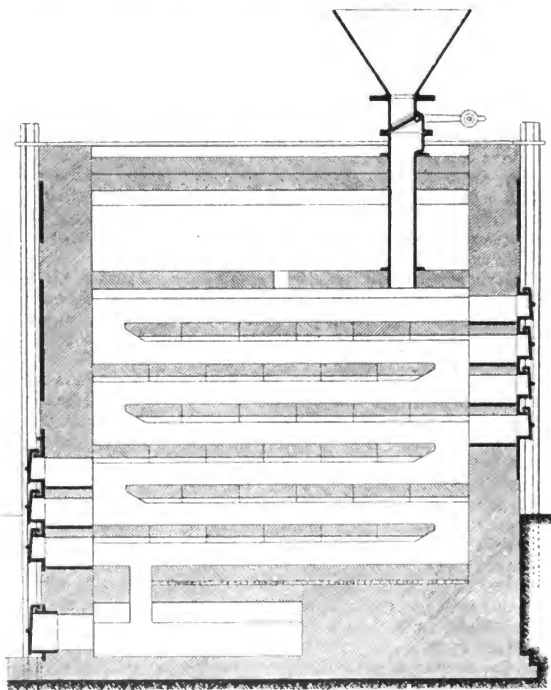


FIG. 41.—BURNER FOR "SMALLS" PYRITES.

is equal to 1.0 lb. per square foot of shelf surface per hour, as a maximum duty. In some experiments made by the author upon the working of a burner of the pattern shown by Fig. 41, a sample drawn from each shelf just before charging showed the following percentages of sulphur, after oxidation with nitric acid :—

Aguas Tenidas pyrites.....	50%	S.
First shelf	30.8	„
Second do.	14.4	„
Third do.	6.2	„
Fourth do.	4.1	„
Fifth do.	2.0	„
Sixth do.	1.4	„
Burned ore den.	1.2	„

It is not easy to completely desulphurise pyrites, especially when it contains notable quantities of zinc and lead. The sulphates of iron and copper are not difficult to decompose at the temperatures existing in ordinary pyrites furnaces, but the sulphates of zinc and lead are decomposed only with the greatest difficulty at such ordinary temperatures, so that before expressing an opinion on the excellence or otherwise of the performance of a smalls burner, an attempt should be made to ascertain how much of the residual sulphur is due to metallic sulphates and how much to mineral sulphides.

Another type of burner is shown by Fig. 42. This was not devised for the combustion of small pyrites but for that of the spent oxide of iron of the gas works. This material consists of free sulphur, hydrated peroxide of iron, tarry matters, sawdust, or other organic matter, and sometimes a considerable quantity of carbonate of lime, so that unless the burner is properly designed to deal with such a mixture, the sulphuric acid produced from it is likely to be an expensive preparation. The best form of kiln for the combustion of this material is shown in Fig. 42.

The foregoing construction is almost exactly as originally designed by Hills, of Deptford, in the sixth decade of the last century, but it has been modified from time to time, with no beneficial result, however, by several contractors who have not understood the principles upon which it was originally constructed. At first sight it may appear a counter part of the smalls pyrites burner, but there are several departures from that type which should be duly appreciated. The sawdust and other organic matters burn almost as readily as the free sulphur, and the tendency is for the carbon to burn only to carbon monoxide, while the sulphur is apt to simply distil in such an atmosphere, and to escape unburned, while the imperfectly oxidised products react upon the nitric acid in such a manner as to very materially increase the amount used, when the combustion is not complete. Unlike the pyrites-smalls burner, the charge of material is placed upon each shelf of the burner and left there until the whole of the sulphur has been burned off, the products of combustion passing away from each shelf separately into a vertical flue which conducts them into a forward and return flue underneath the lowermost shelf of the burner, and from which they ascend into a similar forward and return flue over the top shelf, before entering the nitre oven. In this way the topmost and lowermost flues act as combustion chambers, and the air supply must be so regulated as to completely burn up all combustible matters before the gases leave the top flue for the nitre oven. A small orifice in the door,

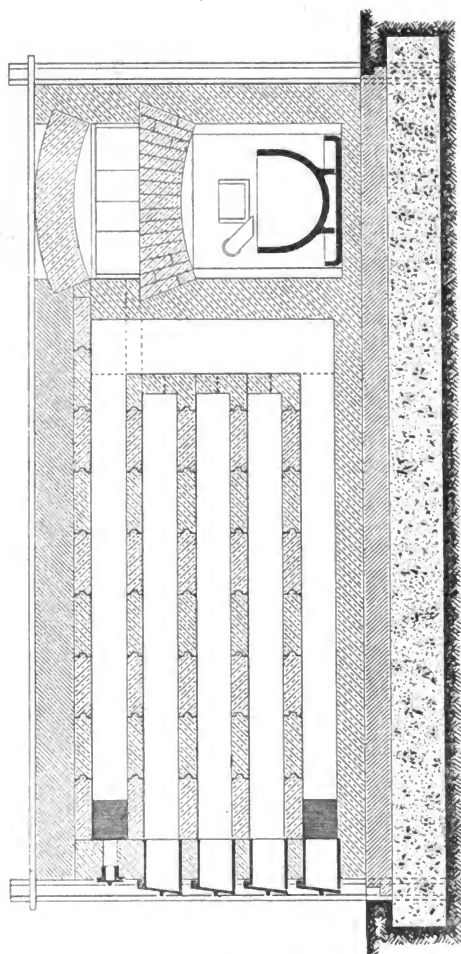


FIG. 42. — HILL'S SPENT OXIDE BURNER.

closed with a mica plate is a very useful addition for observing whether the combustion has been completed. The burnt material is not pushed from shelf to shelf as in the smalls burner, but is drawn with a rake into a proper receptacle from the front. The operation of drawing out the burned oxide is rather a dusty one, and some users have modified the construction so as to allow the burned material to be pushed out at the back of the kiln into a dust chamber, but as the cloud of dust is raised in the strong draught leading to the tower and chambers, it will readily be seen that the ingenuity displayed in modifying the original design would have been much better spent in devising means for the avoidance of dust, when drawing from the front of the kiln. The Hills oxide kiln is not suitable for material low in sulphur, as it ceases to burn well when the sulphur contents fall below 30 per cent., and with about 20 per cent. the material will scarcely burn at all. There are thermo-chemical reasons for this, which are sufficiently explained by the following equation:—



A burner of the pattern illustrated, with three shelves in each vertical row and six shelves in each horizontal row, will deal with $3\frac{1}{2}$ tons of material containing 50 per cent. of sulphur per 24 hours, which is 1·5 lbs. per square foot of shelf per hour.

There is yet another type of kiln or roaster remaining to be described ere the subject of hand furnaces is concluded, and that is brought into requisition through the inability of certain sulphides to burn without the assistance of extraneous heat. Zinc sulphide, technically known as "black jack" or blende cannot be burned in ordinary kilns or without the assistance of external heat, and this is also the case with the sulphides of nickel and some of the natural sulphides of copper and with the matte of these metals. For the calcination of blende, a special kiln or multiple muffle furnace is employed, a longitudinal section through which may be seen in Fig. 43. These kilns are used on the Continent for dealing with blende when it is desired to utilise the sulphur dioxide that is evolved, and one is working at Flint, in North Wales, calcining ores from the Leeswood zinc mines.

Perret has found by experiment that when dealing with natural mineral sulphides in a current of air, ordinary iron pyrites commences to lose sulphur at about 440° C., and chalcopryrite, magnetic pyrites and copper mattes at 525° C., while blende does not commence to decompose till 750° C. is exceeded. In actual practice experience teaches that approximately 900° C. must be reached to ensure complete calcination, or rather, complete desulphurisation, as the sulphate of zinc that is first formed requires this temperature for its destruction. It is easy now to see why the muffles containing the particles of blende require to be strongly heated. Hollway, in a paper read before the Society of Arts in London in 1879, stated that the temperature of combustion of zinc sulphide in air was 1992° C., and Bode, in his treatise on sulphuric acid, gave it as 2850° C., which latter figure is no doubt utterly incorrect, but Hollway's figure was erroneous even if the theoretical quantity of air could be used, which experience has proved can never be the case in practice. In fact, the gases

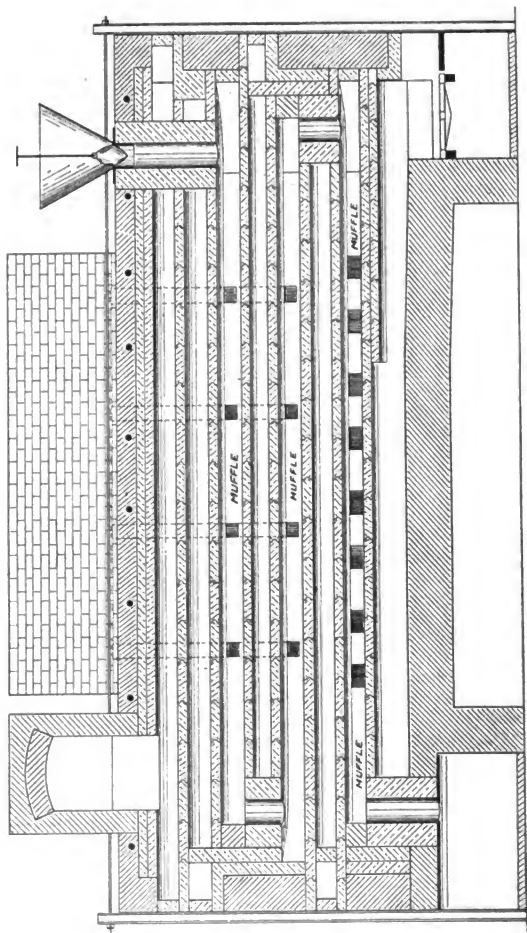


FIG. 43.—FURNACE FOR ROASTING ZINC-BLENDE (Longitudinal Section).

coming away from blende kilns, even of the best pattern, seldom contain 90 per cent. of sulphurous anhydride, so that we may approximately reckon that the air necessary for the proper roasting of blende is double that required theoretically. Let us now see what is the maximum possible temperature for pure blende, with this excess of air :—

Heat of formation : $\begin{matrix} 84807 & 69248 \\ 97 & 96 & 336 & 81 & 64 & 48 & 336 \\ \text{ZnS} & + & 6\text{O} & + & 24\text{N} & = & \text{ZnO} & + & \text{SO}_2 & + & \text{O}_3 & + & \text{N}_{24} \end{matrix}$
 42971 Heat of formation of one molecule of ZnS.
 Specific heat $\begin{matrix} \cdot 125 & \cdot 155 & \cdot 2182 & \cdot 244 \\ \text{C.H.U. per pound molecule :—} & 10\cdot 12 & 9\cdot 92 & 10\cdot 47 & 81\cdot 98 \end{matrix}$
 we have, therefore :—

$$1(81 \times \cdot 125) + (64 \times \cdot 155) + (48 \times \cdot 2182) + (336 \times \cdot 244) = 84807 + 69248 - 42971$$

from which we find that

$$t = 990^\circ \text{C.}$$

In the blende kiln shown in the illustration (Fig. 43) the consumption of fuel varies from 14 to 20 per cent., according to the richness of the ore, the latter figure being required for a 50 per cent. blende. The temperature of the top muffle into which the ore is first charged averages 600°C. , the centre muffle 700°C. , whilst the lower muffle or that which receives the first heat from the fire, is kept at about 900°C. or even more. When the kiln is in normal work, and the raw mineral contains 26 per cent. of sulphur, it will be found reduced to 16 per cent. at the end of the first muffle, to 10 per cent. at the end of the second, and to about 10 per cent. at the end of the third.

It will be found on calculation that a very large quantity of heat is removed from the muffles with the products of the operation. For every 97 parts of pure blende calcined, 64 pounds of sulphur dioxide, 48 pounds of oxygen, and 336 pounds of nitrogen pass away at a temperature of 600°C. , which is equal to 61,426 C.H. units, or more than one half of that emitted by the combustion of the zinc sulphide. But this is not all, as there is the loss caused by drawing the zinc oxide and gangue at a temperature that can be put down at 990°C. The loss by zinc oxide would be 10,023 C.H. units, and if we presume the mineral to contain 50 per cent of pure blende, the gangue would carry away with it 19,200 C.H. units. In all, these losses amount to 90,649 units out of the 111,084 units emitted by the blende. From a perusal of the foregoing figures it would appear that the heat of combustion of the zinc sulphide was sufficient to enable the reaction to proceed, but we know from experience that such is not the case. Indeed no account has been taken into the calculation of the heat lost by radiation, etc. Ninety-seven pounds of zinc sulphide means 194 pounds of the raw material, and this will require one-fifth of its weight, or 39 lbs. of coal to calcine it. 39 lbs. of coal of a calorific power of 7,000 C.H. units is equivalent to 273,000 C.H. units, and if we imagine that 20 lbs. of the products of combustion pass away from the furnace at a temperature of $1,000^\circ \text{C.}$, we have a loss of 185,640 C.H. units in them. In fact,

87,360 C.H. units have disappeared from the coal combustion and 20,435 units from the combustion of the blende.

The firegrate heating one of these sets of three muffles is 32 inches square, and burns about 5 lbs. of coal per square foot per hour. The bed of the muffle is 27 feet in length, with a width of 4 feet, and as four tons of blende are roasted per day of 24 hours, this means an output of 1.1 pounds of mineral per square foot per hour.

But the tendency of late years has been to replace hand furnaces,

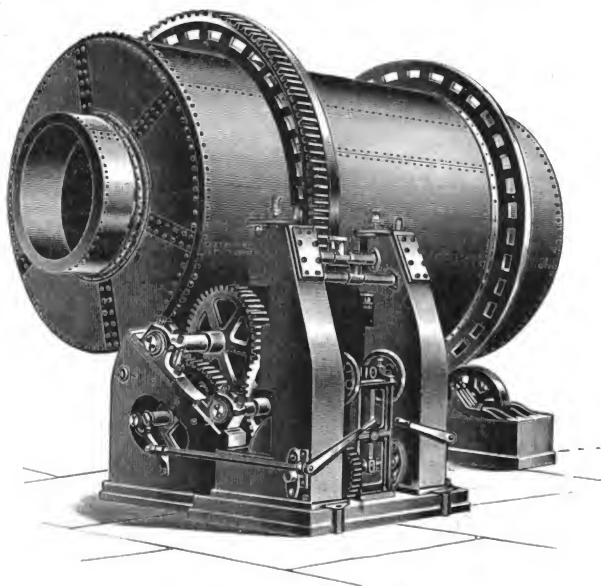


FIG. 44.—THE BLACK-ASH REVOLVER.

whenever possible, by the mechanical furnace, and so completely has this been done in some industries that men could not now be found to work the older hand furnaces, were they required. The old reliable race of hand furnacemen has disappeared from the chemical trade.

Mechanical furnaces are of many styles and patterns. In some of them the beds are stationary while the rabblers or stirrers are moved by power; in others the whole appliance is made to move, and in this type there is sufficient variation to need separate illustration. The ordinary

black-ash revolver, such as is shown in Fig. 44, may be described as consisting of two main parts, the furnace proper and that portion containing the charge of materials undergoing the heating operation. Some revolvers have been heated by producer gas, and the furnace is, of course, modified to suit the combustible. In the illustration the furnace is not shown, but a sufficient description of it may be found on page 13. There is one point, however, that should be considered in designing, and that is, the upper portion of the furnace chamber should not form a combustion chamber for the gasified fuel, as in such an event the arch covering it would be quickly destroyed by the high temperature. Only a portion of the combustion of the fuel should be done in the furnace, and the hanging ring, which separates the furnace proper from the revolving body, should be of such dimensions as will allow of the entrance of sufficient air to complete the combustion. What is required is a short but intense flame that will radiate its heat quickly to the materials undergoing treatment. The revolving body is usually constructed of boiler plate, and is lined with fire-clay blocks, which must be selected according to the quality of the work to be performed. For work with semi-fused alkali, metalline bricks (page 109, Vol. I.) will perhaps have a long life, while in other cases the best Stourbridge pot-clay will be found the best material for lining. No general rule, however, can be laid down, as much depends upon the character of the flame and how the furnace is manipulated. Lining blocks are usually $7'' \times 4'' \times 4''$, the neck blocks for the same purpose are $12 \times (6'' \times 4\frac{1}{2}'') \times 6''$, while what are known as mixing blocks are built in longitudinally, and these, projecting through the lining, carry up a portion of the charge during a revolution of the cylinder and let it fall again on to the remainder below, and thus accomplish the mixing. The lining of a revolver is a costly affair, and is not unattended with risk to the brick-setter.

The revolvers employed in alkali making are of varying capacities, but there is no doubt that the medium sizes, to decompose from 160 to 200 tons of salt-cake per week, are the most economical both in fuel and repairs. Whether large or small, the charge is worked off in about two hours, or, as a rule, 11 charges in 24 hours, which means 66 charges in the week. The weight of salt-cake in each charge runs from 30 cwts. in the smallest size to 50 cwts. in the medium sizes, while the mammoth furnace erected some years ago in Widnes, 30 ft. long by $12\frac{1}{2}$ ft. diameter, is stated to have worked up 400 tons of salt-cake per week, with a consumption of 200 tons of firing slack. Each charge of salt-cake weighed over eight tons. In a revolver of medium capacity, of which the author once had charge, the weekly average of salt-cake worked up was 138 tons with 65 tons of firing slack. As will be seen from the illustration, the revolving body of the apparatus turns on the trunion wheels upon which it rests, being turned by a driven pinion working into a circular rack which encompasses the body. Provision is made for both quick and slow motion; the slow motion, which is employed for the greater portion of the operation, gives one revolution of the body in about 7 or 8 minutes, while the quick

motion gives about six revolutions per minute. Some revolvers are run faster than this, but there is nothing to be gained by it except heavier repairs.

A furnace of precisely the same type as the black-ash revolver is used for roasting ores in the United States. It is made by the Allis-Chalmers Co., under the name of the Bruckner furnace, in various sizes ranging from 6ft. in diameter and 12ft. long to 8½ft. in diameter and 28ft. long. For roasting silver and lead ores this furnace makes about four revolutions per hour, and requires about 4 H.P. to drive it. Some of these furnaces are fitted with movable fire boxes—that is to say, the furnaces proper are built on wheels, and made to run on a railway track, so that the source of heat can be immediately removed and passed on to some other furnace standing ready charged to receive it.

When we lengthen the revolver and reduce its diameter we arrive at a type similar to what was once known in Cornwall as the Oxland calciner. A similar furnace is now made in the States by the Allis-Chalmers

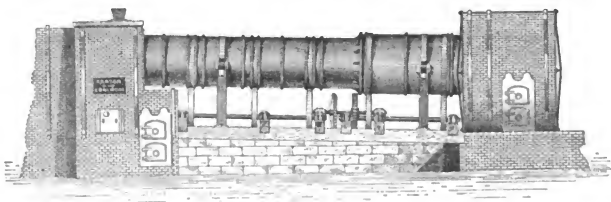


FIG. 45.—THE WHITE-HOWELL TUBE FURNACE.

Co., under the name of the White-Howell furnace. It consists of a long iron cylinder lined for a portion of its length with fire brick, supported on friction rollers, and made to revolve by suitable gearing; the material to be roasted being fed into the upper end of the cylinder by a screw feed apparatus, while the calcined ore is allowed to drop from the lower end into a suitable chamber placed next to the fireplace to receive it.

Another application of the tube furnace is drawn from the sand brick industry. The sand from which the bricks are made is dried by allowing it to pass through an inclined tube furnace as shown in Fig. 46. The heating agent is finely powdered coal dust, which is blown into the mouth of the tube with the necessary quantity of air. Combustion takes place instantly, and the products of combustion pass out of the tube into the chimney carrying the moisture with them, and as these gases are extremely hot (about 300° C.) some of them are taken back to the fire end, and made to pass through the cylinder again. It is the absence of hand labour that makes this form of drier economical.

The rotary tube furnace is now growing in dimensions, and is being extensively adopted in the cement manufacture. At Wyandotte, in Michigan, U.S.A., where Portland cement is made, the cement slurry, compounded from field clay, and the caustic mud from an alkali works, is run into a rotary calciner thirty feet in length and three feet in diameter by means of a two-inch pipe, and the fully calcined cement clinker falls out at the lower end of the tube.

The standard rotary cement kiln made by the Vulcan Iron Works at Wilkes-Barre, Pa., U.S.A., may be seen in Fig. 47. It is six feet in diameter and sixty feet long, and will produce about 190 barrels of cement clinker per day. The slurry is fed into the upper end of the tube by means of a blowing fan exactly as in the smaller tube furnace already described, and the clinker is discharged through the firing hood, and can be dropped into cars, elevators, or conveyors. The power required to rotate the tube averages about 6 H.P. These kilns are usually lined with 12 inches of fire brick for a distance of about 15 feet from the firing end and the remainder of the

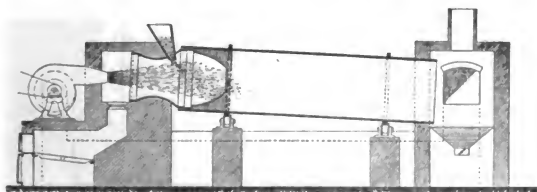


FIG. 46.—TUBULAR SAND DRIER.

length with 9 inch fire bricks. The tube is set on a pitch of three-quarters of an inch to the foot, and the speed of rotation may be controlled by means of the Reeves variable speed drive, which is fitted to each furnace.

Messrs. F. L. Smidth and Co., of Copenhagen, have also devoted considerable attention to rotary cement kilns, several of which are working at the Klagstorp cement works in Sweden. These kilns are each six feet in diameter and 72 feet long, with a separate chimney to each, and the necessary coal crushing and coal feeding plant. Each furnace turns out about 180 tons of cement clinker per week, while the temperature of the gases entering the chimney is still above 300°C . The Smidth furnace is also fired with finely ground coal dust. The coal is first dried in a rotary drier by means of air, heated by being drawn through the red-hot clinker, and when it is thus dried, it is passed through a ball mill where it is roughly ground, finally going through a tube mill for finishing. The ground fuel is of such a degree of fineness that it leaves but 4 per cent. upon a 100-mesh sieve and 20 per cent. upon one of 180 mesh. This finely ground coal is elevated into circular hoppers, from which it is taken by a small measuring worm, fitted with a counter, so that the furnaceman knows exactly how much

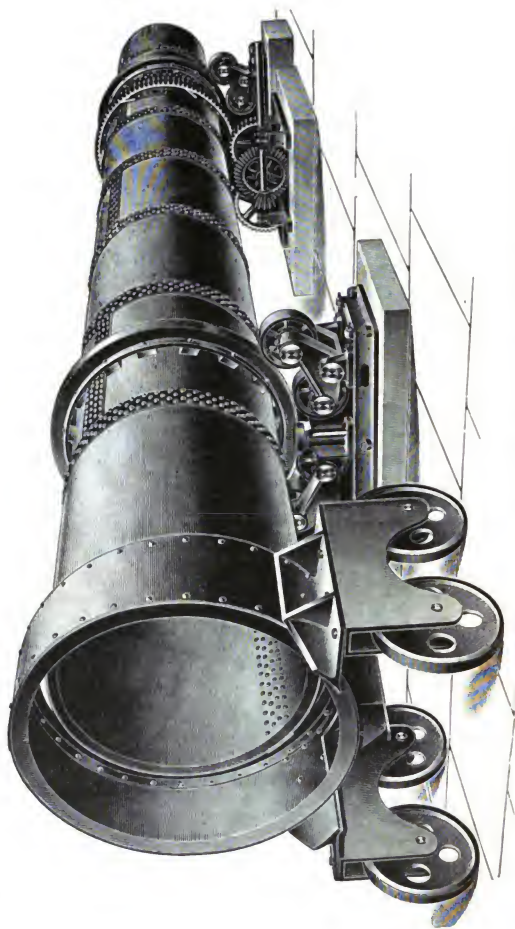


FIG. 47.—STANDARD ROTARY CEMENT KILN. (Made by the Vulcan Iron Works, Wilkes-Barre, Pa., U.S.A.)

coal he is burning. The coal dust falls from the worm into an injector, where it meets the current of air from the blast fan, and is carried away with it into the furnace. The coal-grinding plant must be kept constantly at work, as it is not safe to store finely pulverised coal in any quantity. This kiln consumes rather more than 7 cwts. of fuel per ton of cement clinker produced, and the fuel used for power purposes, including the mills for grinding, does not exceed 1.25 cwts. per ton of cement.

The powdered coal system has also been adopted for steam boilers, there being one 30ft. \times 8ft. Lancashire boiler working with good results at 345 Cable-street, London, E. The fire-bars are completely removed, and the flues lined with fire bricks for about ten feet of their length. A bridge and baffle of special form is placed inside each flue. The feed of the coal dust is worked entirely by the draught, and the hoppers containing the coal over each feeder are fed by a worm conveying the powder from the pulverising plant. The cost of grinding the coal will of course vary with the size of the installation, but one shilling per ton of total cost may be considered an outside figure, and the corresponding advantages must not be left out of the calculation if a cheap fuel can be used. The Central Cyclone Co., Ltd., who instal this system, say that one of their Class I. pulverisers will give 18—20 cwts. per hour, taking 19 H.P. to drive it; a No. 2 will give 35-40 cwts. per hour, consuming 24 H.P., while a No. 3 will yield 60 cwts. per hour with 40 H.P.

From some results of boiler trials published by the Central Cyclone Co., Ltd., a 30ft. \times 8ft. Lancashire boiler, having 930 square feet of heating surface, with an economiser of 900 square feet of surface, evaporated 4,550 lbs. of water per hour on the coal-dust system, with an efficiency of 79 per cent., which will be found to compare favourably with the results of a Lancashire boiler, fired in the ordinary way, detailed on page 260 of Vol. I.

From the revolver pattern of furnace we may turn to the horizontal calciner, when it will be found that these mechanical furnaces may also be divided into two kinds—*a*, those in which the furnace bed is stationary, the material undergoing calcination or heating being moved or stirred by means of revolving rakes, stirrers, or ploughs, and *b*, furnaces in which the bed is made to revolve, the rakes, stirrers or ploughs remaining stationary. Each of these classes may be again divided into intermittent dischargers and continuous dischargers.

Perhaps the first idea of a horizontal mechanical furnace for chemical purposes was due to Furlong (B.P. 46, 1871), who erected a furnace in Manchester a few years later. This furnace was afterwards improved by Mactear, and the mechanical furnace of *b* type is now known as the "Mactear furnace," and is largely employed for calcining soda-ash, and for many other similar purposes.

The construction of the Mactear furnace may be seen in Fig. 48, from which it may be gathered that it consists of a revolving pan or furnace bed, circular in form, running upon guide wheels placed underneath. The furnace is placed at one extremity of the diameter, and the exit into the flue at the other extremity. A row of moving stirrers reaches across the

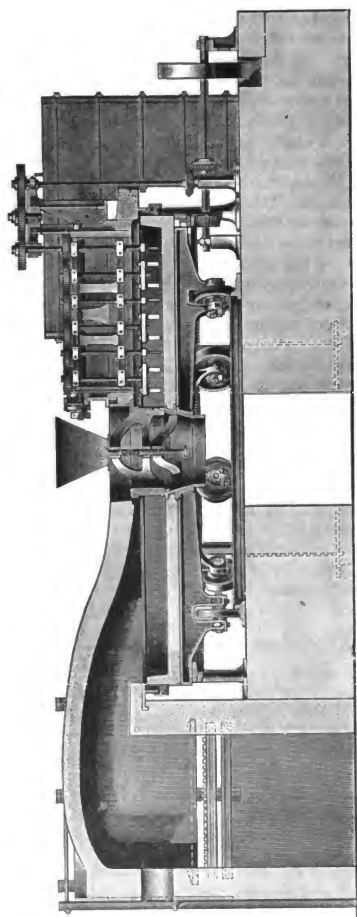


FIG. 48.—THE MACTEAR FURNACE.

radius, extending from the outlet flue to the centre of the bed, or thereabouts, and as these are practically in what may be termed the shadow of the flame, they last for some time without needing repair. By the combined motion of the revolving bed and the rotary stirrers, the material undergoing calcination is being continually turned over and exposed to the action of the heat. Either coal fuel or producer gas may be employed in these furnaces with equal advantage. In the ammonia soda process these furnaces are employed in densifying the soda-ash that has been already lightly roasted in another form of mechanical furnace. For such a purpose, each furnace will turn out nearly 250 tons per week, but when employed in roasting wet carbonate salts ($\text{Na}_2\text{CO}_3 \cdot \text{H}_2\text{O}$) each furnace will only turn out from 80 tons to 90 tons per week of 144 hours. Each furnace consumes about 30 tons per week of ordinary slack fuel. As to cost, a Mactear furnace, built in the best manner possible, complete, with foundations, brickwork, and flues, will run far away into £1,200, to which must be added the extra cost of elevators, conveyors, ash floor, and such like appurtenances.

The Godfrey calciner is of Welsh origin, and is somewhat of the description of the Mactear furnace, though it differs from it in some important particulars. In these furnaces a sector of the top arch is left open to the air, and here the ploughs are placed, and, being in the open air, they always remain cool. The fire-grate is attached to the calciner at a spot adjoining this sector opening, and the flame passes round the calciner to the other side of the opening, where it leaves the furnace. The top arch of the furnace is placed very low, so that the heat is effectively deflected upon the material undergoing calcination. Twelve Godfrey calciners have recently been erected at the works of the Smelting Corporation, at Ellesmere Port, in Cheshire, where they have been employed in roasting Australian slimes containing about 20 per cent. of lead sulphide and 33 per cent. of zinc sulphide. A Godfrey furnace 20ft. in diameter, having a hearth area of 280 square feet, will roast 5 tons of Australian slimes per 24 hours to about 1·0 per cent. of sulphur at a cost of about 6s. per ton for fuel, labour, power, and repairs. The furnaces at Ellesmere Port were moved at the rate of one revolution in two minutes by an electro-motor, and it was estimated that the power taken to drive was less than 2 H.P.

Furnaces with fixed hearths have their representatives in the Davis furnace, the Brown roaster, the Wethey roasting furnace, and a number of others it is scarcely necessary to mention. The furnace made by the F. M. Davis Iron Works Co., of Denver, Colorado, shown by Fig. 49, is a long hearth reverberatory with a hearth 150ft. long by 12ft. in width. The furnace is heated with lateral fireplaces stationed at definite distances apart so as to equalise the intensity of the flame.

The rabble consists of a rake fitted with adjustable teeth, which is fixed between long side bars at each end. These side bars have long racks upon their lower sides which work into spur wheels driven by the main gearing. When the spur wheels are set in motion the rabble frame is caused to travel forward, until, having reached the end of its journey, the direction of the

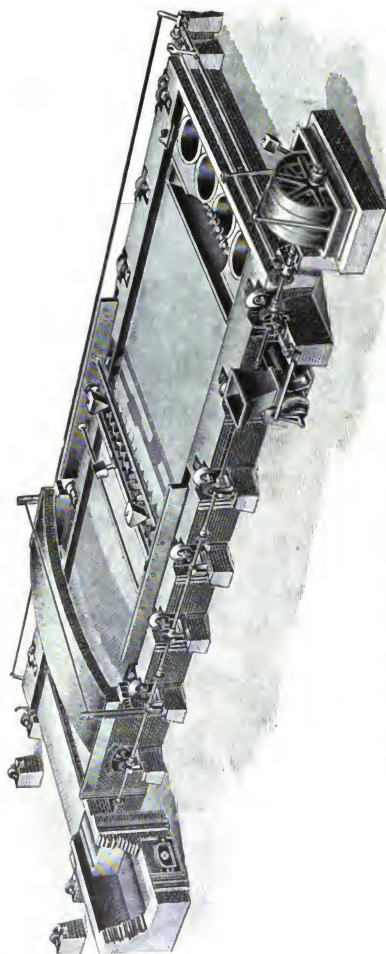


FIG. 49.—THE DAVIS ROASTING FURNACE. (F. M. Davis Iron Works Co., Denver, Col.)

drive is automatically reversed, and the rabble moves back again with the rake blades standing well above the ore lying upon the hearth. The rabble remains constantly in the furnace, and so is exposed to the full heat ; means are therefore taken to keep the working parts cool. The side bars and the three hollow transverse bars are kept full of water, the loss by evaporation being automatically made up after every journey through the fire. The illustration shows a portion of the arch removed to exhibit the rabble, and the operating mechanism.

The Brown furnace, already mentioned, is built in several forms, which are known as the "straight hearth," the "elliptical," the "round," and the "horseshoe" patterns, each of which has been designed to suit local conditions. When made other than straight, the stirrer carriages—mentioned again later on—are drawn by an endless steel wire rope, which runs in the inner conduit, and is supported on small horizontal grooved wheels, placed

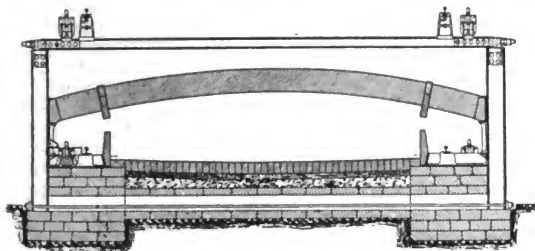


FIG 50.—THE BROWN STRAIGHT-HEARTH FURNACE.
(The Allis-Chalmers Co., Chicago.)

sufficiently near to each other to cause the rope to conform to the curve of the furnace. The rope is driven and kept taut by passing it round a system of wheels driven by a small steam engine provided for the purpose.

The Brown "straight hearth" furnace is built of any length from 50ft. to 180ft., and to a width of 10ft., a cross-section through one of them being shown in Fig. 50.

In the conduits formed by the slotted walls and the extension walls of the furnace, shown in the illustration, rails are placed, upon which the trolleys run, supporting the stirrer arms which project through the slotted walls. The stirrer shoes, resembling miniature ploughshares, are fastened to that portion of the arm which extends over the hearth, and these shoes dip into the ore lying on the hearth to the depth of several inches. The stirrer carriages are moved through the hearth in the direction of the firebox by two endless roller link chains which pass over sprocket wheels placed at both ends of the furnace outside the roasting hearth. After passing through the hearth each carriage returns over the top of the furnace in the direction

of the flue, on tracks similar to those placed in the conduits, and having reached the end of the arch it passes downwards into the hearth again. Sheet-iron flap doors, hinged at the top, are placed at both ends of the roasting hearth, keep out the cold air; they remain closed except when lifted by a stirrer carriage in passing in and out.

By the foregoing construction, the operating mechanism is protected from the furnace heat and fumes, and the carriages, by passing over the top of the furnace in the open air, have time to cool off, and the stirrers do not become overheated. The slotted walls are formed by building fire-clay blocks into the arch as is shown in the illustration, together with a second block which projects upward from the hearth. The skew-backs of the arch are steel channels supported on short cast-iron columns, the intervals between the columns being $3\frac{1}{2}$ ft. by 12 in. high, and these openings extending the entire length of the hearth form a continuous slot on both sides, which permits of ready access at any point for repairs without the necessity of having to tear down the brickwork to get at the interior of the furnace. As to capacity, the Allis-Chalmers Co. state that silicon ores containing up to 3.5 per cent. of sulphur require 15 square feet of hearth per ton; mattes, which usually contain from 18% to 20% of sulphur, need 45 square feet per ton to bring the sulphur contents down to 4.0%, while the roasting of iron sulphide concentrates, containing from 35% to 45% of sulphur, require 60 square feet per ton to reduce the sulphur to 0.5%.

One feature of the Brown furnace is the provision of auxiliary fire-boxes along the sides of the furnace. These fire-boxes have a grate surface each of 15 square feet, and this is sufficient to heat about 300 square feet of hearth. The repairs to these furnaces are high, and from all that has been published, economy of fuel is not a feature of the design, but the saving is in manual labour, which is all important where labour is scarce. A Brown furnace, on blende roasting, put through 12 tons of ore per day of 24 hours, and burned from 9 tons to 10 tons of coal slack, the mineral containing from 80 to 85 per cent. of zinc sulphide.

The Wethey furnace, a section through which is shown in Fig. 51. has a roasting hearth 12 ft. wide and 100 ft. to 130 ft. long, and is somewhat similar in design to the Brown furnace, though it differs in some important particulars. In the Wethey furnace, the skewbacks forming the arch-supports are rolled joists arranged as shown in the figure, so that it is possible with this form of construction to arrange a slot the whole length of the furnace, as in the Brown method of building. The slots in the side walls are closed by small overlapping pieces of sheet steel, pivoted at the upper corners so that the axle of the stirring carriage can lift them during its passage along the hearth. The stirring carriage is worked by chains from each end of the furnace, and these are apt to give trouble. A Wethey furnace at the Joplin works of the Empire Zinc Company possessed a hearth 12 ft. wide and 164 ft. long, and, with two men per shift to attend it, has been stated to have roasted 20 tons of mineral per day of 24 hours.

There are not many furnaces of the rabble and chain type to be found working in the United Kingdom. From time to time designs incorpor-

ating these ideas have been introduced, tried and found wanting, the consensus of opinion being that what is saved in the lower priced labour of the furnacemen is lost by the higher priced mechanic's labour during repairs. As already mentioned, locality may upset the balance of the equation, and any intending user of such furnaces should make special inquiries, not only as to the cost of repairs, but to the number of days the furnace is out of working order, and also, what is not less important, the amount of fuel consumed. Air drawn in in excess, especially if it is cold air, causes an enormous waste of fuel.

The mechanical furnaces just described possess only one hearth, and are thus exposed to excessive radiation from both above and below, but a multiple hearth furnace was introduced by McDougall in 1868 (B.P. 270. 1868) for roasting small pyrites and burning the spent oxide from the gas

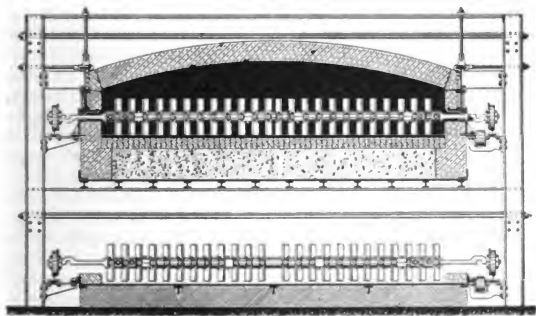


FIG. 51.—THE WETHEY ROASTING FURNACE.
(The Allis-Chalmers Co., Chicago.)

works. When this furnace was first introduced, the air necessary for combustion was supplied by a fan or blower, but this was soon afterwards discontinued. The McDougall furnace was introduced into a fair number of works between the years 1870—1880, the author having had several under his notice during that period dealing with different materials, but in nearly every instance they were discarded after a long trial on account of the large amount of dust carried over with the gaseous products of the calcination. This fault has not been remedied even in later furnaces of this type, and should be seriously investigated by intending users of mechanical furnaces when the purity of the manufactured product is of moment.

The McDougall furnace may be seen in Fig. 52, from which it will be gathered that it consists of a series of shelves, placed one above the other, over which revolve ploughs of such a pattern that the material undergoing combustion is gradually moved, either to the centre of the shelves, or

away from the centre to the periphery. In actual operation, the raw ore is fed into a hopper upon the top of the furnace, and is taken down from shelf to shelf by the action of the ploughs, until it reaches the outlet on the bottom shelf in a thoroughly oxidised condition. The ploughs are

so set that the teeth upon one shelf take the material from the centre to the peripheral openings, through which it falls on to the next shelf below; the teeth of the ploughs now cause the material to converge towards the central opening in that shelf, the next plough taking it to the periphery of the shelf, and so on.

In furnaces of this description, care must always be taken to make the gas passages from shelf to shelf large enough. If the passages are too small there is some danger of their becoming choked at the point where the material falls from the shelf above, and, even if chokage does not take place, the area becomes so restricted that the high temperature passing through such a narrow aperture fuses the finer particles into hollow spheres which, as such, are readily carried away by the draught.

A McDougall furnace was erected at the Hardshaw Brook Chemical Works, in St. Helens, in 1875. It was one of the original pattern, with forced draught, burning about 25 tons per week of small pyrites, but the draught carried away with it nearly four tons weekly of the finest dust, a tithe of

which was fused into the spheres already described. When some of this fine dust was spread over a glass plate, placed at an inclination of one in five, a very gentle tapping of the plate caused these spheres to leave the general body of the dust and roll down the inclined plane, by which means they were collected. When natural draught was substituted

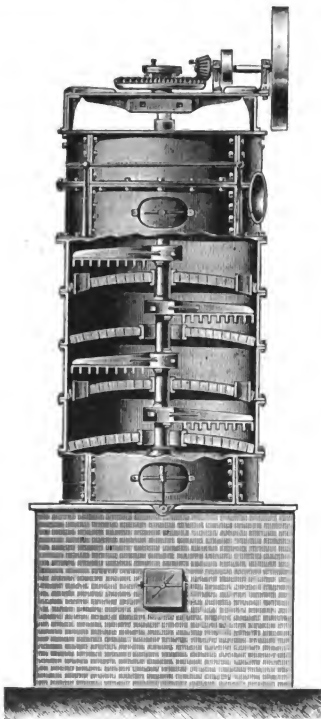


FIG. 52.—McDOUGALL'S MECHANICAL CALCINER.

for the forced draught, this objection, to a great extent, disappeared. The longevity of the central shaft is always a source of anxiety, in furnaces of this kind, but this can always be remedied, as was done later by McDougall, by making it hollow, with air for the cooling agent, as was also done later by Herreshoff, and with water, as was applied by Frasch. The water cooling is by far the most efficient.

The Herreshoff furnace is shown in Fig. 53, and does not seem to differ from the McDougall pattern except in very minute details. The work of the McDougall furnace has already been stated; similar results may be obtained from the Herreshoff pattern, but the dust difficulty is one that has yet to be overcome.

The mechanical multiple hearth furnace serves as an example of that type where the material about to undergo combustion is fed in on the top of a series of shelves, and, travelling from shelf to shelf downwards, is gradually denuded of its combustible matter, until delivered from the lowest shelf completely burned. In such furnaces the shelves become heated, and radiate heat above and below them, so that it is possible to roast a lower grade of ore in them than when an extended surface of bed is exposed to the absorbing influence of a comparatively cool brickwork arch. The air needed for combustion enters at the lower part of the furnace, and the hot gases flowing over and between the shelves keep the whole construction hot enough to allow combustion to take place.

Several furnaces of the foregoing type are to be found in the United States, such as the Pearce multiple hearth or turret furnace, the Falding furnace and the Haas furnace, but it is not necessary to mention them further as the principles upon which they all work are thoroughly set out in the McDougall pattern.

The mention of the cooling of portions of a furnace with a water current brings us naturally to what are styled water-jacket furnaces; of which, perhaps, the illustration Fig. 54 will give all necessary particulars.

These furnaces are extensively used in the States for smelting copper ores and for concentrating matte. The jacket is made of flange steel,

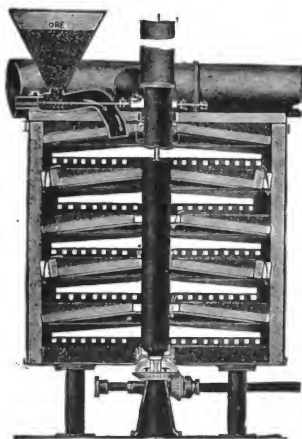


FIG. 53. THE HERRESHOFF FURNACE.

the sheets being either rivetted or welded together as preferred. The jacket is surrounded with a removable wind-box; to this the blast-pipe is connected, an arrangement insuring equal distribution of the blast to each tuyere and hence a perfect delivery of air to every part of the charge, thereby producing a very uniform melting zone. The tuyeres, being

entirely within the water space of the jacket, are protected from the action of the heat, and consequently do not burn out or cause any trouble whatever. Peep-holes with removable mica coverings are placed in the wind-box opposite the tuyeres.

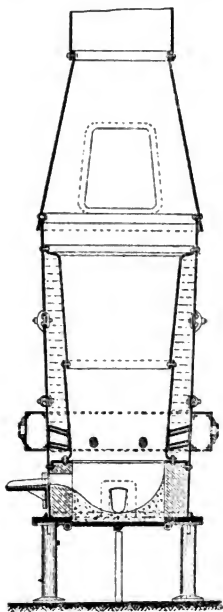


FIG. 54.—
STEEL WATER-JACKETED
FURNACE FOR COPPER ORES.

The curb is a sheet-steel casing made by prolonging the outer plate of the jacket some distance below the water space. The curb rests on a cast-iron base-plate, which is supported on four columns. There is a large circular opening in the centre of the base-plate, closed by two drop doors attached to its under side. The furnace requires only a few fire-bricks to line the curb and base-plate, after which "steep" a mixture of fire-clay and coke-dust is tamped in and cut out to form a crucible of the proper shape. These water-jacket furnaces are superior to all others in simplicity, strength, perfection of water circulation and capacity. They will run for months without a stoppage. For low-grade pyritic ores the larger of these furnaces may be used without an internal crucible, the materials as soon as they reach the bottom in a molten condition being permitted to flow out of the furnace into an exterior crucible or forehearth mounted on wheels. This forehearth may be either lined with fire-brick or water-jacketed.

As an instance of the working capacity of such furnaces as these, it may be stated that the 36-inch furnace made by

the Allis-Chalmers Co., of Chicago, which is the size in most demand, has a capacity of 25 to 50 tons per 24 hours, and requires about 1,000 gallons of water per hour.

Rectangular water-jacketed furnaces are also made for the smelting of both lead and copper. That illustrated by Fig. 55 shows the type of furnace erected at Ellesmere Port for the winning of lead from Australian

slimes. A furnace having a section of 12 ft. \times 3 ft. 6 ins. will pass through it about 250 tons of ore per day, when worked with a blast pressure of 1.5 lbs. per square inch. In a furnace of this size, which has a height of 18 ft., there are seven tuyeres on each side, and the fusion actually takes place in direct contact with the steel sides of the furnace, which is kept free from damage by the water jacket, in which a constant current of water is circulated. The quantity of water required is, of course, very great, but, if cooled sufficiently to allow it to be re-pumped, the quantity actually evaporated need not be excessive. In any case, however, it would not pay to purchase such water from local authorities, but when the cost of pumping has only to be considered, the expense is trifling. In a small

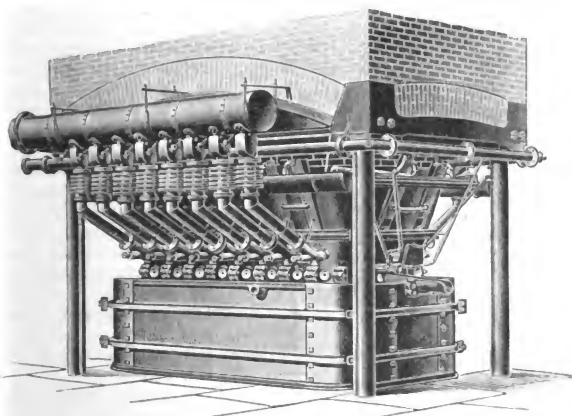


FIG. 55.—WATER-JACKETED FURNACE.
(Colorado Iron Works Co.)

water-jacket cupola, known to the author, the ore treated weekly was 320 tons. It consumed 93 tons of coke during this period, and 1,248,000 gallons of water for the jacket, which passed away just under the boiling point, and was not utilised in any way.

A water-jacketed smelter in which the steam generated in the water-jacket is used for scrubbing out the fume driven off from the furnace is shown in Fig. 56; it is made by the Union Smelter Manufacturing Co., of St. Louis, U.S.A.

Beyond calling attention to the slag outlet and the tapping hole for matte, the bustle pipe bringing air from the blower, and the tuyeres, there is nothing requiring description so far as the smelter is concerned, but

the dust-collector requires a little more extended notice. An examination of the smelting operation will show that the fume liberated from the smelter is carried by the blast into the apparatus on the left of the furnace, where it meets with the steam of the water jacket, and is further scrubbed with a stream of water running down the inclined plates of the condenser. Much of the fume is arrested and is carried down with the water current into the base of the apparatus, from whence it is run into a well, from time to time, to settle.

With some ores this method of fume washing is satisfactory, but with others this is not the case, as was found in the recently constructed works of the Smelting Corporation, at Ellesmere Port, in Cheshire. In this case the fume was zinc oxide, accompanied with more or less lead oxide, and this method of wet precipitation did not yield a merchantable

article on account of the admixture. When the operation was changed to one of dry precipitation, or natural subsidence, the zinc oxide did not contain more than 2.0 per cent. of lead. There is another point connected with wet precipitation that must not be overlooked. The sulphurous acid present in the gases tends to dissolve oxides of the zinc group, eventually to form sulphates, which may be lost to the manufacturer without this fact is recognised.

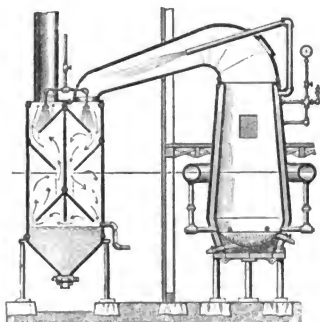


FIG. 56.—UNION COMBINATION SMELTER.

Another form in which heat is applied is by interposing the fuel in layers between the material undergoing the heating process. This may be illustrated by the cement kiln or the lime kiln, the latter of which has become a recognised fixture of the larger chemical establishments.

In England there is no economy whatever practised in the burning of lime, and, as a consequence, the amount of fuel used is very high. In the High Peak district the slack employed for burning is usually 22 tons for every 100 tons of limestone, whereas in some districts in France 5.25 tons of coke serves to calcine the same quantity of stone.

Let us consider what goes on in the ordinary lime-kiln. The temperature at which limestone commences to decompose is about $1,100^{\circ}\text{C.}$, and as the specific heat of limestone is 0.21, it follows that 231 c.h. units will be necessary to heat one pound of it to the decomposing temperature.

TABLE 12.

SPECIFIC HEATS OF SOME COMMONLY OCCURRING SUBSTANCES.

Acetic acid (96° C.)	·5220	Lead (at 300° C.)	·0401
Acetone	·5150	„ sulphate	·0872
„ vapour	·4125	„ sulphide	·0508
Air	·2379	Litharge	·0509
Alcohol (0·793)	·6220	Magnetic Iron oxide	·1678
„ (80° C.)	·7694	„ pyrites	·1602
„ vapour	·4513	Marble and limestone	·2099
Alumina	·1976	Mercury	·0333
Aluminium	·2135	Naphthalin	·3100
Ammonia	·5080	Nickel	·1086
Aniline	·5120	„ (at 300° C.)	·1403
„ (12° C.-138° C.)	·5231	Nitric acid (1·30)	·6614
Arsenic trioxide	·1278	Nitrogen	·2440
Arsenide of iron	·0864	Oak	·5700
Barium nitrate	·1523	Oxygen	·2182
Benzol (10° C.)	·4071	Pine wood	·6500
„ (50° C.)	·4502	Platinum	·0329
„ vapour	·3754	„ (at 1600° C.)	·0398
Bismuth	·0308	Potassium	·1729
Calcium carbonate	·2086	„ bichromate	·1894
„ fluoride	·2149	„ carbonate	·2162
„ sulphate	·1966	„ chlorate	·2100
Carbon dioxide	·2164	„ chloride	·1729
„ disulphide	·2390	„ nitrate	·2387
„ monoxide	·2479	„ sulphate	·1901
Chalk	·2148	Pyrites (FeS ₂)	·1300
Chlorine	·1214	Quicklime	·2169
Chloroform (60° C.)	·2384	Silica	·1913
„ vapour	·1568	Silver	·0571
Coal	·2411	Sodium	·2934
Coke	·2008	„ borate	·2382
Copper	·0951	„ carbonate	·2727
„ oxide	·1420	„ chloride	·2140
Cupreous pyrites (CuFeS ₂)	·1310	„ nitrate	·2782
Diamond	·1468	„ sulphate	·2311
Ether	·4810	Stannic oxide	·0930
„ (0·76)	·6600	Sugar	·3011
Ferric oxide	·1757	Sulphur	·2026
Flint glass	·1900	„ dioxide	·1553
Gas retort carbon	·2036	Sulphuretted hydrogen	·2423
Glycerine	·5760	Sulphuric acid (1·84)	·3346
Gold	·0324	Toluol (10° C.—99° C.)	·4400
Graphite (natural)	·2018	Water vapour	·4750
Hydrochloric acid (1·2)	·6000	Wolfram	·0980
„ „ Gas	·1845	Wollastonite (CaSiO ₃)	·1780
Hydrogen	3·4046	Wood charcoal	·2415
Iron (at 0° C.-100° C.)	·1138	Zinc	·0955
„ (at 700° C.-1000° C.)	·2179	„ chloride	·1362
Kryolite	·2379	„ oxide	·1248
Lead	·0314	„ sulphide	·1230

In order to break up the chemical constitution of limestone, in other words, to drive off the carbonic acid, 370 units are required, and these disappear absolutely. But as only one part of lime is left in the kiln for every two parts of limestone introduced, it follows that one half of the 231 C.H.U. must remain with the heated lime while the other half goes forward with the gases, as the specific heat of carbonic acid is almost exactly the same as that of limestone. This is only correct, however, when the lime is discharged at 1,100° C., and the gases escape at the same temperature. In such a case a minimum of 601 C.H. units would be required for each pound of limestone calcined. If it could be so arranged that the lime were discharged from the kiln at the same temperature as that of the limestone introduced into the mouth of the kiln, and provided that the gases left at a similar temperature to that of the ingoing air, all loss by radiation being suppressed, 370 C.H. units should be sufficient to calcine one pound of limestone. Nothing like this has been attained in the High Peak district, where 7.5 cwts. to 8 cwts. of slack are to-day required to produce one ton of lime, the latter figure being the almost universal practice.

The foregoing figures show that each pound of limestone requires in actual practice 0.22 lbs. of slack, which, at 6,000 C.H. units for each pound, amounts to 1,320 C.H. units, so that the thermal efficiency of the fuel in a Buxton lime-kiln is:—

$$\frac{100 \times 370}{1320} = 28 \text{ per cent.}$$

The heat losses consist of —(a) loss by the discharge of hot lime from the kiln, (b) loss by the discharge of heated gases, and (c) loss by radiation from the kiln. Losses *a* and *b* can be in a great measure suppressed, *b* especially, by limiting the amount of air used for the combustion of the fuel, and by passing the gases after combustion through a sufficient superstratum of uncalcined limestone, while it will be seen in the next illustration that the loss *c* must be very small indeed.

For the production of 370 C.H. units of heat, one sixteenth of a pound (0.062) of slack is necessary, so that to supply this heat to a ton of limestone, 1.24 cwts. of slack should be sufficient.

With the above comparison before us, let us now consider some figures from lime-kilns running in France, where fuel is dear. A large kiln, having a capacity of 4,300 cubic feet, is yielding 40 tons of lime per 24 hours, consuming four tons of coal of very good quality. This corresponds to 71 tons of limestone charged, a ton of which must therefore consume 1.13 cwts. of coal, or, in other words, one pound of limestone has required in actual practice 0.056 pounds of coal. We have already seen (Vol. I., page 267) that one pound of good Yorkshire coal can develop 7,800 C.H. units, so that it will be easy and safe to reckon out the efficiency of this kiln on these figures. It is:—

$$\frac{370 \times 100}{7,800 \times 0.056} = 84.7 \text{ per cent.}$$

therefore the loss of heat from all sources, hot lime, waste gases, and radi-

ation combined, could not have exceeded 15·3 per cent. In the Buxton lime-kilns the loss is 70 per cent.

The lime-kilns employed in and about a chemical works, where the carbonic acid is required for use, such as in the ammonia-soda process or for the manufacture of carbonate of ammonia, or for the saturation of carbolate of soda in the operation of separating the phenol from coal-tar distillates, are closed kilns, of which the best pattern is shown in Fig. 57. The exhausting and compressing engine is connected with the top of the kiln, which should be very correctly proportioned to the work required of it.

A lime-kiln of this pattern will yield approximately one-third of its total cubic contents above the bars as lime per 24 hours, from which it is easy to find the exact dimensions for any given output.

A kiln known to the author as doing good work was 16 ft. diameter at the base and 5 ft. diameter at the summit, there being a burning height of 30 ft. above the bars. The following figures will show the composition of the gases from lime-kilns of this type, the fuel used being gas coke. The fuel employed is calculated upon the limestone charged into the kiln:

	1.	2.
Carbon dioxide....	36·4	39·6
„ monoxide..	4·0	2·4
Oxygen	0·2	0·4
Per cent. coke used	10	8
Height of kiln in feet	24	30

Before leaving this portion of our subject, some attention should be paid to such operations as the burning of brimstone for the manufacture of "brimstone sulphuric acid." This is an industry that is fast dying out, so that the

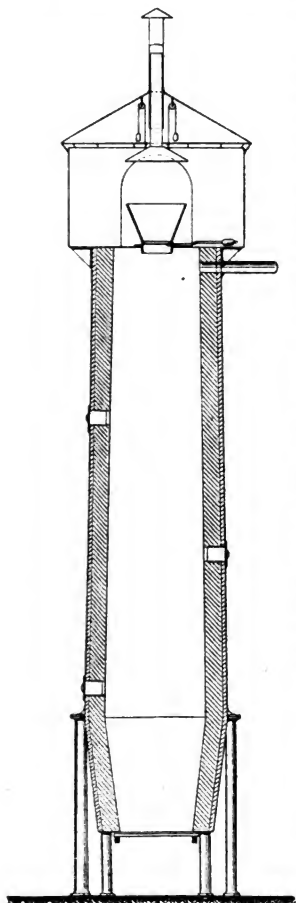


FIG. 57.—CLOSED LIME-KILN.

operation is only of illustrative importance. When the industry was active, the kiln most in use for the combustion of brimstone was that devised by Harrison Blair, or, at least, modifications of it, for each user modified it somewhat to suit his own ideas. The chief difficulty in burning brimstone lies in preventing the sublimation of unburned sulphur. If the combustion goes on too rapidly the temperature rises unduly, and flowers of sulphur appear upon the cooler portions of the apparatus, unless a further supply of air has been subsequently introduced before the vapour has cooled below the temperature necessary for combustion. We have seen in dealing with the combustion of coal, that from



FIG. 58.—WATER-COOLED SULPHUR-DIOXIDE FURNACE.
(The Sachsenburg Engineering Co.)

12 lbs. to 20 lbs. may be burned upon fire-bars per square foot per hour, but this example cannot be followed in ordinary cases in the usual sulphur kiln. The sulphur kiln has no bars, but an impervious solid bed, and the maximum consumption in the combustion oven does not exceed 2 lbs. per square foot per hour. This rate is regulated by the admission of air. Of course, with properly constructed apparatus, much more sulphur could be burned on a given area than that just mentioned, and such an apparatus would not require any inventive genius, but it is doubtful whether any real advantage would be gained over the employment of the slow-burning Blair kiln. A pound of sulphur in burning to sulphur dioxide gives out 2,165 C.H. units, or 0.27 of that evolved from the combustion of a pound of good coal.

Some years ago McDougall devised a sulphur burner after the fashion of a cast-iron gas retort, various portions of which were cooled by a current of cold water; this cooled the current of gaseous sulphur dioxide and condensed the volatilised sulphur, in fact, kept the combustion more under control than the old type of oven possibly could, and this is of great service in the manufacture of bisulphites. Still more recently the Sachsenburg Engineering Company have devised a furnace for burning sulphur in making sulphurous acid solutions, which is shown in Fig. 58.

The complete installation consists of an air pump, air reservoir, sulphur burner, and counter current cooling apparatus, all of which may be effectively cleaned without taking to pieces. The furnace is made in six sizes and is specially suitable for use in sugar works, starch works and gelatine works, and in fact in all establishments wherein sulphur dioxide is used for bleaching or for the production of solutions.

Heating by Steam. — We may now turn our attention to some of those processes where the heat is transmitted by the agency of steam, a very common method in all chemical establishments. The actual opera-



FIG. 59.—STEAM BOILING JET.

tions of heating stills, and the liquids passing to them, of heating evaporating vessels, or of exchanging the heat of two liquids at different temperatures, will be studied in other chapters, but the principles upon which such operations are conducted must find a place here.

There are two methods of heating liquids by steam: First, by the condensation of the steam in the liquid itself, and, second, by the circulation of the steam in a worm or coil separating it from the liquid. The first method is simple enough, and at one time it was performed by inserting the open end of a steam pipe into the vat, or other vessel, in which the liquid to be heated was contained. What are termed boiling jets are now employed, the construction of which may be seen in Fig. 59. In the old method, the noise produced by the sudden condensation of the steam was very great, and the wear and tear on lead-lined vessels excessive, so that the introduction of the boiling jet was a decided improvement. This jet is constructed upon the principle of the injector, but is so modified that the steam passed by the nozzle is sufficient to nearly boil the volume of liquid which it will draw through the suction or circulating orifices. There is no noise, no wear and tear, and the heating operation is more quickly performed than in the old way.

TABLE 13.

PARTICULARS OF MELDRUM'S STEAM BOILING JETS.

Size number.	Gallons per hour boiled.	Inside diameter of pipes.		
		Live steam.	Exhaust steam.	Water.
1	60	$\frac{1}{2}$ inch	$\frac{3}{4}$ inch	1 inch
2	120	$\frac{3}{4}$ "	1 "	$1\frac{1}{2}$ "
3	200	1 "	$1\frac{1}{2}$ "	2 "
4	300	$1\frac{1}{4}$ "	2 "	$2\frac{1}{2}$ "
5	450	$1\frac{3}{4}$ "	$2\frac{1}{2}$ "	3 "
6	800	2 "	3 "	4 "
7	1200	$2\frac{1}{2}$ "	4 "	5 "
8	1800	3 "	5 "	6 "
9	3200	4 "	6 "	8 "

An illustration of the method of heating with direct steam has already been given on page 249, Vol. I., but we can consider here another problem in which the steam not only heats the liquid but produces the necessary agitation by means of the injection of air, the injector shown on page 448, Vol. I., by Fig. 222, being employed for that purpose.

A causticiser 10 feet in diameter and 12 feet deep will comfortably hold 3,800 gallons of water, 6,000 lbs. of soda-ash, and 3,100 lbs. of quicklime, which constitutes the charge. For an ample agitation over the area of the causticiser $300 \times 78 = 23,400$ cubic feet of air per hour would be necessary, for which a No. 9 compressor (Vol. I., Table 112, page 449) is required. This compressor should be supplied with steam from a 3-inch steam pipe, so as to secure an adequate pressure at the nozzle, and a boiling jet of sufficient capacity to heat up the contents of the causticiser in about one hour should be fitted to an independent steam supply. The apparatus being complete, let us see what quantity of steam would be required to complete the causticising operation in one hour if the materials were provided at a temperature of 10°C .

The number of C.H. units to heat the water would be:—

$38,000 \times (99 - 10)$	3,382,000
Required to heat the soda-ash : $6,000 \times 89 \times 0.273$	145,782
Required to heat the lime : $3,100 \times 89 \times 0.21$	57,939
Required to heat the air : $1,778 \times 89 \times 0.238$	37,661
Heat in the water vapour carried away by the air : $468 \times 0.481 \times 89 \div 2$	10,017
Loss by radiation, etc., from causticiser : 450 sq. ft. at 60°C .	28,802
	<u>3,662,201</u>

On the other side of the account we must not omit to give credit for :—

The heat of solution of the soda-ash : $6,000 \times 5.64 \div 106 \dots$ 319

The heat of formation of the hydrate of lime : $3,100 \times 270 \dots$ 837,000

837,319

We get, therefore, as a net result, 2,824,882 C.H. units as the necessary quantity of heat to complete the operation. If the steam be employed at 50 lbs. pressure (see Vol. I., page 248) the weight and volume necessary will be :—

$$\frac{2,824,882}{553} = 5,108 \text{ lbs.} = 33,429 \text{ cb. ft.}$$

and the water vapour condensed in the liquid is $5,108 - 234 \text{ lbs.} = 4,874 \text{ lbs.}$; the 234 lbs. being the vapour carried away by the air current, used for agitating. This quantity is difficult to gauge exactly, but the foregoing estimate is based upon the assumption that the loss of water vapour is just one-half of that which would have been carried away, had the maximum temperature prevailed during the whole time of the operation.

At one time, such operations as the foregoing were performed in many chemical works by means of exhaust steam, the exhaust pipe being loaded to blow off at 5 lbs. per square inch, so as to give the steam head enough to travel through a sufficient depth of liquor. Some amusing stories could be told of the thermics of those days. The director of one of these works where the utilisation of waste steam was carried to absurdity was wont to argue that low pressure steam was better and more efficient than high pressure steam, as the latent heat of 5 lbs. steam was 531 C.H. units, while the latent heat of 50 lbs. steam was only 503 units. "A little learning is a dangerous thing"; let us look at the problem from another point of view.

We have already seen that the operation in the causticiser would consume 5,108 lbs. or 33,429 cb. ft. of steam at 50 lbs. pressure; but at 5 lbs. pressure this weight of steam would have occupied 102,160 cubic feet. Now, if the steam pipes had been proportioned to deal with the larger volume at the lower pressure, which they were not, no harm would have been done, but to attempt to carry 5 lbs. steam through pipes of small diameter delayed the operations of heating to such an extent that in many works exhaust steam fell into disuse, live steam taking its place. Let us now see the size of steam main required in each case.

The formula that will serve our purpose may be found on page 213, Vol. I., but it will be found more handy to work with Table 91, on page 295 of the same volume. Let us turn to it. We have 5,108 lbs. of steam to move per hour, and the table tells us that at 50 lbs. pressure, 5,369 lbs. per hour will flow through a six-inch pipe, one hundred feet in length, with a velocity of 50 feet per second. If a velocity of one hundred feet per second is allowed, then a five-inch pipe would be ample. If now we turn to steam at atmospheric pressure it will be found that 5,313 lbs. will flow through a length of one hundred feet of twelve-inch pipe at a velocity of

50 feet per second, while, at a velocity of 100 feet per second, a nine-inch pipe would be sufficient.

What would suffice for steam at atmospheric pressure would also be suitable for steam at 5 lbs. pressure per square inch, and this is the practical way of using the table. When greater accuracy is desired for scientific purposes, the formula (2, page 293) should be employed.

The alternative method of heating liquids by means of steam-jackets or steam coils is followed in many instances where the condensed water would be an objection if it were allowed to intermingle with the liquid that was being heated, or where the purpose of heating was that of evaporation. The theoretical side of this operation is a very complex subject, and is far from being solved yet. The consideration of this aspect of the question will only be considered here in brief, as a further consideration by those requiring it is better made by a study of such works as Hausbrand on *Evaporating, Condensing, and Cooling Apparatus*,* or Peclet's *Traité de la Chaleur*.† In both of these works many practical figures are given, and many theoretical deductions made from them, which deserve careful study, but the author does not propose here to approach the subject in the same manner, but in a way that may possibly recommend itself to the reader.

In using steam jackets or steam coils, there is a good practical rule to go by :—(a) One square foot of heating surface of thin copper (one-twelfth of an inch in thickness) will raise the temperature of 20 gallons of water from 10°C . to 100°C . in one hour when the steam admitted to the jacket or coil has a temperature of 144°C . Or (b) One square foot of heating surface will evaporate to the air 2 gallons of water per hour from 100°C . with steam of the same temperature as in a.

In a the mean temperature difference between the liquid and the initial pressure of the steam is 81°C ., and from this figure the transmission of heat from the steam to the liquid corresponds to 223 C.H. units per square foot per hour for each 1°C . of mean temperature difference. But if we allow for a drop in pressure of the steam within the heating chamber, of one atmosphere, between its entry and its exit, the mean temperature difference becomes 74°C . and the C.H. units transmitted will be 244 per square foot per hour for each 1°C . of mean temperature difference.

In b the mean temperature difference between the boiling liquid and the initial temperature of the steam is 44°C ., and the heat transmission corresponds to 244 C.H. units per square foot per hour for each 1°C . of mean temperature difference. But, as in a, if we allow for a drop in pressure of the steam within the jacket or coil of one atmosphere, we get a mean temperature difference of 39°C ., and a passage of 276 C.H. units per square foot per hour for each 1°C . of mean temperature difference.

The foregoing figures only hold good for water; for viscous liquids the heat transmission is much less, and will be considered in a future chapter. The figures, also, only hold good for thin copper, as the separating medium; when wrought-iron, cast-iron, or lead is employed, the efficiency of the heating surface is sensibly affected. This may be seen from the following

* London: Scott, Greenwood & Co. 1903.

† Paris: G. Masson. 1878 Fourth Edition.

diagram, which gives the ratio of heat transmission for the metals in common use, and of varying thickness in the walls.

This diagram (Fig. 60) is not given as an absolutely correct series of ratios, but it will serve until someone produces a better. It is the result of some observations of the author with iron and lead surfaces, and is sufficiently near to be a guide in designing plant of this kind. The vertical figures on the left hand of the diagram are the ratios for various thicknesses of metal compared with copper of one millimetre, the thickness being represented by the horizontal rows of figures. The top row is divided to show an inch in hundredths, while the lower row corresponds to millimetres.

The foregoing are good practical rules, but are by no means maximum figures. In an experiment cited by Peclet as being made by Havrez in Belgium, a copper coil, with a heating surface of 0.544 square metre (5.86 square feet), was placed in an iron vessel containing 100 kilos. of water at 20° C. The temperature of the steam was 149° C. (53 lbs. per square inch), and when the water had reached the boiling point, it was found that 207 kilos. of water had been collected from the coil per square metre per hour—which is equal to 4.14 gallons per square foot per hour. Peclet has recorded that as much as 6 gallons of water has been evaporated per square foot per hour, and Hausbrand (page 32) cites an experiment with a copper pan holding 159 gallons with a heating surface of 15 square feet, which heated 22.7 gallons of water from 13° C. to 100° C. per square foot per hour, and evaporated 2.71 gallons per square foot per hour, with steam at 3 atmospheres.

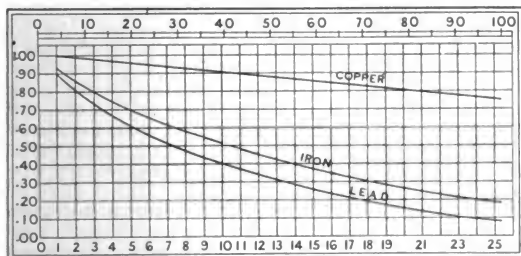


FIG. 60.—SHOWING THE RATIOS OF HEAT TRANSMISSION.

The experiments with the foregoing pan are of sufficient interest to quote here in full, as it will bring out what is often overlooked in such operations, and that is, that the absolute amount of heat transmitted through the walls of the heating chamber—if one is allowed to use the expression—grows less and less as the temperature of the liquid approaches that of ebullition.

TABLE 14.

FROM HAUSBRAND (page 32).

(The last column has been added by the author.)

Interval. Minutes.	Temp. of water in pan. °C.	Excess pressure over atmos.	Calories transferred per 1 sq. m. per hour with 1° C. diff. in temp.	C.H. units transmitted during each interval.
0	13°	0	0	0
5	30°	.4	1,224	27,000
5	47°	.7	1,530	27,000
5	64°	1.2	1,690	27,000
5	80°	1.75	1,950	26,430
5	93°	1.85	2,090	20,650
3	100°	1.95	2,045	18,550*
30	100°	2.0 to 2.6	80 litres evap.	16,000

* Calculated for a five-minute interval

It will thus be seen that during the first three periods of five minutes each the heat passed through the walls of the vessel was identical, and at its maximum the transmission gradually decreasing as the temperature of the liquid rose, while during a five-minute period of the time occupied by evaporation from 100° C. the heat transmitted was only about 60 per cent. of that transmitted during the first interval of five minutes.

In a paper read in 1897 before the Manchester Association of Engineers by Mr. O. M. Row, an experiment was described in which 21 gallons of water were raised from 7° C. to 100° C. in 106 minutes, with steam at 100° C. in one square foot of heating surface in a vertical cylindrical tube. This is equal to 12 gallons per hour per square foot of heating surface, while with the Row indented tube (Vol. I., page 291) the 21 gallons was raised to the boiling point in 58 minutes under similar conditions of steam and heating surface.

As illustrating the combined effect of the nature of the material of which the walls of the heating chamber is constructed with the thickness of the walls, we may take another example from practice. A cast-iron inner vessel surrounded with a jacket presented a heating surface of 34 square feet. The vessel contained 108 gallons, and the jacket was fed with steam at 122° C., by which means the contents were raised from 10° C. to 100° C. in one hour. This is a very low result, being but 3 gallons per square foot of heating surface per hour, but as the thickness of the walls of the vessel containing the liquid amounted to one and a quarter inches, the low heat transmission is readily explained.

In a paper read by Dr. H. Claasen before the International Congress of Applied Chemistry at Berlin in 1903, it was pointed out that the ordinary

formula for the transmission of heat through a conducting medium

$$W = k q \frac{t_1 - t_2}{d}$$

in which W is the quantity of heat, q the area of the surface, $t_1 - t_2$ the difference of temperature between the two surfaces, d the thickness of the partition, and k the coefficient of conductivity of the material of this partition, gives a result about thirty times too great when it is applied to the problem of heating a liquid by means of a steam tube or coil immersed in it. The difference between the results of theory and practice he accounts for by the fact that the steam in condensing forms a layer of water upon the surface of the tube, forming a comparatively stationary layer. The thickness of this stationary portion depends upon the adhesion of the water to the metal, on the fluidity of the water, and the velocity of the moving layer next to it. The higher the temperature, the lower is the viscosity of the water, and consequently the thickness of the stationary layer is smaller. After the heat has passed through these two layers of liquid and through the metal wall it meets on the other side a stationary layer of the liquid that has been heated, and it must pass through this layer before it reaches the bulk of the fluid. What has been said about the internal layer applies also to the external stratum, so that it will readily be seen that the heat must be transferred in turn from the steam to the moving layer, from the moving layer to the stationary layer, from this to the metal, then to the outside stationary layer, and finally from that to the liquid. During each of these operations there is a fall in temperature, the sum total of which is far greater than that between the two surfaces of the metal itself. The researches of Austin enable some conception to be formed of the total thickness of the layer of liquid in the transference of heat from a metal wall to water under various conditions. With boiling water that is not stirred, the resistance to the transference of heat is equal to that offered by 1.2 to 2 cm. of iron; energetic stirring diminishes the resistance to that of 0.75 cm. of iron. If the state of agitation be the same, the resistance appears to be independent of the quantity of heat that passes through, that is, it is directly proportional to the difference in temperature. If the water be neither stirred nor boiling, the resistance may be as great as that of 10 cm. of iron, but agitation reduces it to less than that of 1 cm. of iron. If the state of agitation be constant, the resistance increases as the temperature decreases.

It is Claasen's opinion that the foregoing facts show clearly the influence of motion of the liquid in diminishing the thickness of the stationary layer, and demonstrate the importance of keeping the liquor in a state of agitation. The dimensions of the layer of liquid, it was pointed out, may be calculated from the fact that 1 mm. of water offers the same resistance to the passage of heat as 100 mm. of iron or 120 mm. of brass. The following illustration will give a clearer idea of Dr. Claasen's contentions:—

The foregoing way of stating the case must not be allowed to hide the real facts which exist in practice. If we refer again to Hausbrand's experiment detailed on page 122, we shall find that 27,000 c.h. units passed through the wall of the heating chamber for the first three periods of five minutes

each, 26,430 units during the next five minutes, 20,650 during the next period, while between 93° C. and 100° C. the C.H. units transmitted through the heating surface only amounted to 18,550. At the boiling point, during the actual evaporation of a portion of the water, there were but 16,000 C.H. units transmitted, by the 15 square feet of the heating surface of the pan.

Heat transmission is, however, usually expressed in terms of the difference in temperature between the heating medium, and the liquid to be heated, but as the operation is one of progression it is clear that there will be many differences between the temperatures at the commencement and end of the operation. It is also clear that for any ordinary calculation one number must represent that difference, and this is generally styled the "mean difference in temperature" or the "mean temperature difference." Up to quite recently, investigators have been satisfied to take the arithmetical mean of the varying temperatures into their calculations when dealing with this subject, but Grashof* has shown that the real temperature difference is not always the arithmetical mean, and as it is quite easy to obtain the correct figure from Grashof's formula, we may as well see how it can be ascertained, first, however, going through a calculation by the old method, and one in which, in the majority of cases, the error is so small as to enable it to be used for practical work.

In a well-constructed pan, steam at 30 lbs. pressure (135° C.) is admitted into the coil, which is short and well drained. The liquid (water) in the pan, possesses a temperature of 15° C. at the commencement and 100° C. at the end of the operation. What is the mean temperature difference?

$$\text{Ans. } 135^{\circ} - \left(\frac{100^{\circ} + 15^{\circ}}{2} \right) = 77.5^{\circ} \text{ C.}$$

Grashof's more exact method shows 78.7° C.

To give another example: In the author's ammonia still, the spent liquid at 100° C. is made to pass through a coil immersed in a vessel called the economiser (Fig. 62), containing the gas-water that is ultimately to be distilled. The spent water leaves the coil at about 38° C., while the cold gas-water entering the vessel at 10° C. leaves it at 70° C. What is the mean temperature difference?

$$\text{Ans. } \frac{100 + 38}{2} - \frac{70 + 10}{2} = 29^{\circ} \text{ C.}$$



FIG. 61. DIAGRAM TO ILLUSTRATE THE STATIONARY AND MOVING LAYERS ON STEAM HEATING PIPES.

* Theoretische Maschinenlehre Bd. I.

Grashof's method, by the use of formula (v), is as follows :—

$$\frac{t_a - t_e}{\log_e \frac{t_a}{t_e}} = \text{the mean temperature difference,} \quad (v)$$

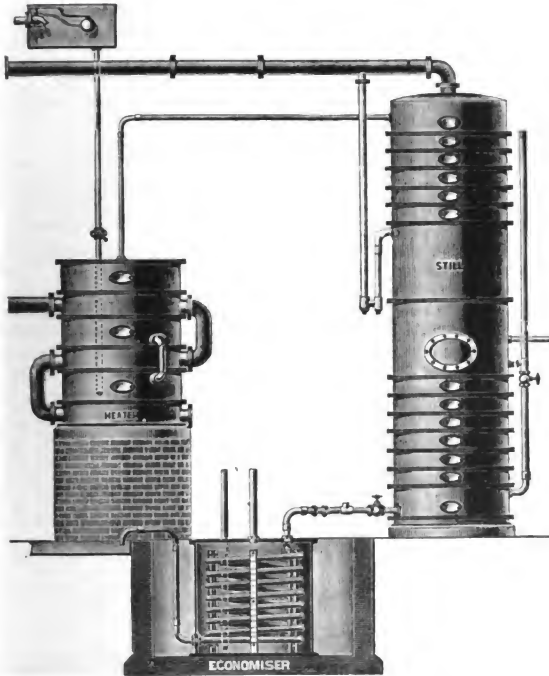


FIG. 62.—THE DAVIS AMMONIA STILL.
(Showing Economiser and Heater.)

so that in the case of the ammonia still just mentioned :—

$$\frac{t_a - t_e}{\log_e \frac{t_a}{t_e}} = \frac{30 - 28}{0.069} = 29^\circ \text{C.}$$

where t_a = the greater difference in temperature between the two liquids,
and t_e = the lesser difference in temperature.

It will be seen that the results obtained by the two methods are identical in this instance, and the student should note that Napierian or hyperbolic logs are used in the denominator of the fraction. This is not apparent in the English translation of Hausbrand's book.

In a still of the pattern shown in Fig. 62, 200 gallons of gas-water are dealt with per hour, or, say, 2,000 lbs., and it will be found that the liquid has gained 60° C. in temperature in the hour during its passage through the economiser. This is:—

$$2,000 \times 60 = 120,000 \text{ Centigrade heat units,}$$

and as the coil possessed a surface of 66 sq. ft., and the mean temperature difference was 29° C., it is evident that:—

$$\frac{120,000}{66 \times 29} = 62 \text{ C.H. units per sq. ft. per hour}$$

for each 1° C. of mean temperature difference. The coil was constructed of ordinary wrought iron steam tubing, with walls 5 mm. (0.2 in.) in thickness.

In problems of this kind, the specific heat of the liquids involved must always be taken into account, and, in most cases, the weights also. We may call the relative weights P and P' , their specific heats s and s' , and their temperatures $^{\circ}t$ and $^{\circ}T$, from which we are able to find the temperature of equilibrium were they mixed without the presence of any separating medium. Indeed, with a separating partition, the same temperatures of equilibrium would be reached, but more slowly, according to the thickness, the extent of its surface, and the material of which the partition is constructed. The formula for ascertaining this condition of equilibrium is:—

$$\frac{P s t + P' s' T}{P s + P' s'} \quad (w)$$

In the case of water or liquids of equal specific heat, the temperature would ultimately become $\frac{^{\circ}t + ^{\circ}T}{2}$; but if there were, say, 200 gallons of water on one side of the partition at 100° C., and 100 gallons on the other side at 60° C., we should have:—

$$\frac{P t + P' T}{P + P'} = \frac{(2,000 \times 100) + (1,000 \times 60)}{2,000 + 1,000} = 87^{\circ} \text{ C.}$$

as the temperature of equilibrium.

The design of jacketed pans does not present many difficulties, but with steam coils the case is very different, as it will be found that the same extent of heating surface will give different results according to the way in which that surface is made up. A coil of copper tubing 2 in. in diameter and 60 ft. in length will evaporate 1.25 gallons of water per square foot per hour, with a mean temperature difference of 44° C. between the initial steam and the boiling water; while a coil 4 in. in diameter and 30 ft. long will evaporate 1.98 gallons per square foot per hour under similar conditions. If, however, we employ the same length of tube as in the first instance, but divided into 10 tubes so as to form a battery of ten 6-ft. tubes of 2 in. internal

diameter each, we may under the best conditions obtain an evaporation of 6 gallons of water per square foot per hour with a mean temperature difference of 44°C .

An examination of the laws that govern the transmission of heat through the walls of coils would occupy much more space than can be spared in this work, and the reader is referred again to Hausbrand's treatise for further information. It may, however, be stated that after a series of practical trials Hausbrand has come to the conclusion that the coefficient of conductivity (k) of thin copper tubes may be expressed by the formula:—

$$(x) \quad k = \frac{1,900}{\sqrt{d l}}; \text{ or } k = \frac{1,282}{\sqrt{d l}} \quad (y)$$

where d and l are the diameter and length respectively of the tubes, the measurements being expressed in x in *metres*, and in y by *feet*. In the former (x) the result will be expressed in calories per hour per square metre, and in the latter, in C.H. units per square foot, and in both, per hour; k is a coefficient only to be used as will be presently explained.

From the foregoing we should be able to calculate the heat units capable of being transmitted per hour, and *per contra*, the heating surface necessary to transmit a definite number of units in a given time. In this connection, the ratios of transmission for the thickness and the nature of the material shown in the diagram on page 121 should not be forgotten.

Following out the foregoing figures, we shall find on taking H to represent the heating surface in square feet, and D , the mean temperature difference:—

$$1282 D \sqrt{H} = \text{C.H. units} \quad (z)$$

transmitted per hour, and consequently—

$$H = \left(\frac{\text{C.H.U.}}{1,282 D} \right)^2 \quad (aa)$$

It must be distinctly understood that the foregoing formulæ (z and aa) refer only to steam coils, with steam on one side of the partition, and boiling water on the other.

It will no doubt have been inferred from Claasen's remarks that the transmission of heat through the walls of a tube or plate is affected by the velocity with which either medium passes over the surface. This has been demonstrated by Ser, Joule and others long since, but there are few practical appliances that have

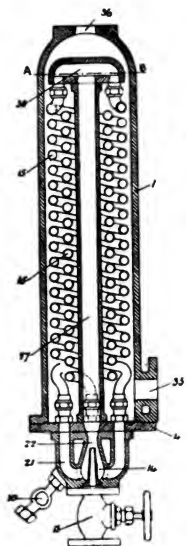


FIG. 63.—
ANDREW'S WATER-HEATER.

been designed with a view to improve this surface action. There is, however, an apparatus now in use to provide a more rapid circulation of the steam in coils or pipes connected with evaporators, water-heaters, condensers, and the like, which promises to be of some importance in this direction. It is shown by Figs. 63 and 64.

Fig. 63 shows a sectional elevation of a water heater having an injector at the lower end. The steam is admitted through the valve 13 and the injector 14 to the tube or pipe 37, thence through the cross-piece 38 to the four coils 15, and back to the suction branches of the injector. The high velocity of the steam issuing from the jet causes the steam contained within the coils to circulate through the cycle described, while the water of condensation is withdrawn through the drain valve 10. Fig. 64 is an enlarged section of the injector portion of the apparatus showing the disposition of the circulating tubes.

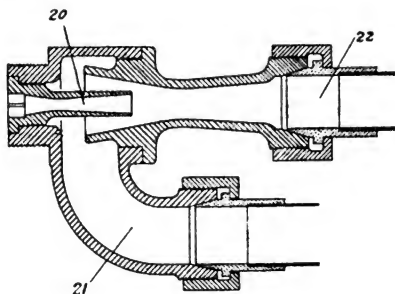


FIG. 64.—ANDREW'S WATER-HEATER.
(Details of Injector.)

Cooling.—In practice, the transmission of heat is by no means confined to heating liquids by means of steam; neither is the object of the exchange of heat always one of heating. It is quite as necessary at times to effect cooling, and if both operations are exercised on products of value some careful calculation is necessary as to the extent of the surfaces involved.

Peclet gives us several illustrations of the work performed by apparatus of this class. In one, having a surface of 1,200 square feet, 1,412 cubic feet of the hot waste water from dye-baths, having a temperature of 56° C., heated up 1,306 cubic feet of clean water from 10° C. to 48° C.; the time is not stated, but, in another trial, it is said that 109 cubic feet of dirty water at 66° C. heated up in one hour 117 cubic feet to 50° C.

In a second installation, an apparatus possessing 800 square feet of cooling surface cooled in one hour 212 cubic feet of water from 100° C. to 22° C., while heating 176 cubic feet to 65° C. A third apparatus, con-

structed with 1,200 square feet of heating surface,⁸ heated 56 cubic feet in 2.5 hours to 65° C., with the same volume of dirty water at 67.5°.¹ These illustrations will serve to show the enormous surfaces that have to be exposed in order to obtain an absolute equilibrium of temperature.

Of course, where ice is cheap, it may be introduced directly into solutions that require cooling, provided the water produced during liquefaction be not detrimental to the process or the product, but it is seldom that this expense can be incurred. It was at one time employed generally in breweries, but all such establishments of any magnitude have now their own refrigerating machine. The heat of liquefaction of ice is 79 C.H. units, which disappears during the process of melting. From this it will be seen that in order to cool 100 lbs. of water (10 gallons) from 10° C. to 5° C., nearly six pounds of ice would be required, which in most cases would be prohibitive.

The transference of heat will come before us again in the chapter on Evaporation and Distillation, but in this place we may study what takes place in the cooler for denitrated acid at the base of a Glover tower of a sulphuric acid plant.

In a plant recently designed by the author, 4,000 lbs. of sulphuric acid at 150° Tw. (1.75 sp. gr.) ran from the tower, per hour, at 149° C., and left the cooler at 15° C. The cooling water entered at 10° C., and left at 60° C. The coils possessed an active surface of 225 square feet. Now as the specific heat of acid at this strength is 0.44, the heat to be transferred is :—

$$P s (t - ^\circ T) = 4,000 \times 0.44 \times (149 - 15) = 235,840 \text{ C.H.U.}$$

The quantity of cooling water would therefore be :—

$$\frac{\text{C.H.U.}}{t - ^\circ T} = \frac{235,840}{60 - 10} = 4,717 \text{ lbs., or } 472 \text{ gallons}$$

per hour, or 1,048 C.H. units per square foot of *lead* cooling surface per hour. This is equal to 12 C.H. units per square foot per hour for each 1° C. of mean temperature difference.

There is another method largely employed for cooling solutions, and that is by means of what is called in breweries and a few other establishments refrigerators. Such an apparatus consists of a series of horizontal tubes, over the topmost of which is a trough in which the hot liquid is contained, and which acts as a distributor. The cooling water enters the lowermost tube, and ascends tube by tube until it leaves the uppermost at a point where it is in contact with the hottest liquid. The hot liquid flowing downwards meets with colder and colder water until it leaves the lowermost tube cooled as completely as the conditions of surface, thickness of moving liquid, and atmospheric temperature will allow.

A transverse section through one of the foregoing refrigerators may be seen in Fig. 65. This form of apparatus generally acts very well, but the tubes must not be too large in diameter, as the greater the velocity of the liquids, within certain limits, the greater the cooling power. Since a very large proportion of the cooling is effected by actual evaporation of the water in this form of cooler, it is evident that in some cases it is better to place the liquid to be cooled within the tubes and to let the cooling water

flow over the outside surface. This was the case with the output from a crude benzol still of a carbonising works. The benzol from the gas was absorbed in heavy oil, and driven off by heating to 110°C . by means of a steam coil, blowing in dry steam at 30 lbs. pressure at the same time. The debenzolated oil required cooling before it was ready for another absorption, and this was effected by running from the still through a pipe refrigerator of the pattern shown in Fig. 65, the hot oil entering the lowest tube and leaving by the topmost, while the water was showered over the uppermost pipe and was nearly evaporated by the heat of the lowest in the series. In cooling

liquids such as beer or wort it may safely be reckoned that one square foot of cooling surface of thin copper will cool 4 gallons per hour from 70°C . to 15°C ., with the cooling water at 10°C .

On pages 20 and 21 of Vol. I., there were given some figures of the cooling installations that have been erected at various times in connection with the recovery of by-products from blast furnace gases, and it was there pointed out upon what different principles such operations may be conducted and yet arrive at the same end. Blast furnace recovery-plants, shale retorting, and the manufacture of coal gas have given us some valuable experience in the direction of cooling large volumes of gaseous products, but there are very few figures available that have been worked out as Peclet would have treated such valuable information.

In the coal-gas industry, the gases entering the hydraulic main from the retorts average about 70°C ., and it is necessary to reduce this temperature to 15°C . The cooling surface necessary for this is variously stated by different writers. The air condensers at Beckett are said to contain four square feet of exposed surface per 1,000 cubic feet made per day. King's treatise recommends 10 square feet per 1,000 cubic feet per day; Newbiggin says 10 square feet per cubic feet per minute;

while Clegg gave 150 square feet per 1,000 cubic feet per hour when the layer of gas is not more than three inches in thickness. We can, however, get some actual figures to work upon. A cooler at the Rochdale-road gas works, in Manchester, had the dimensions of 220 feet \times 20 feet \times 12 feet freely exposed to the air, and possessed a superficial area of 14,560 square feet of cooling surface. Through this cooling chamber there were passed 250,000 cubic feet of gas per hour, which entered at 54°C ., and left at 15°C . Now if we take the sp. gr. of coal-gas to be 0.45, and its specific heat 0.75, we shall be able to see what is the loss of heat per

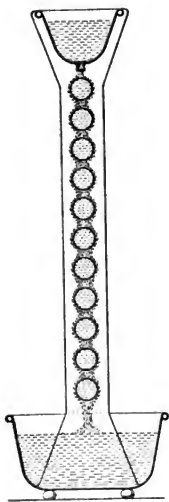


FIG. 65.—REFRIGERATOR.
(Transverse Section).

square foot per hour in this case. It is 17 C.H. units per square foot per hour on an average. At first sight it might appear that the cooling surface was excessive, but on calculation it only measures 3.6 square feet per cubic foot per minute; 2.4 square feet per 1,000 cubic feet per day, or 58 square feet per 1,000 cubic feet of gas per hour. Many more instances of various kinds could be given showing the value of a study of this subject, but we must stop somewhere.

Another method of cooling, and one largely employed now for cooling the condensing water from steam engines, and which may also be used for many other purposes, is that produced by partial evaporation at moderate temperatures in a strong current of air. These coolers are made to work either with natural draught or with artificial mechanical ventilation, viz., a blowing fan. One of the first kind may be seen in the accompanying illustration (Fig. 66), which shows the stream of water to be cooled being sprayed into the interior of a wooden tower, so constructed as to allow a current of air to pass upwards through the spray, which exposes a very large cooling surface to its action. The air has a free entrance to the interior of the tower, through the spaces between the sloping boards, and these boards prevent any water being carried outside the limits of the collecting channel. The cooled water drops from the outside edge of the boards, and is collected round the base of the tower, and from these conveyed to the collecting tank, or wherever it may be required. Where there is a pond or a lodge of water, the tower is unnecessary, as the spray nozzles can be fixed to a circular pipe in such a manner that the cooled water falls into the pond, and is thus collected without further cost.

When the tower is employed, and a blowing fan is employed to replace natural draught, the fan usually absorbs about three per cent. of the power developed by the engine.

The cold air employed acts in two ways. First, by abstracting heat from the hot water and becoming heated thereby, the amount of which can be calculated when we know the temperature of the air entering and leaving, and the weight of the air moved, and second by evaporating a portion of the water, an operation that will be more fully considered in Chapter IV. It may be mentioned here that in towers constructed after the pattern of Fig. 66 the velocity of the air current averages about 10 feet per second within the tower by reason of its becoming heated by the hot water, without the aid of fans; with fans the velocity may be considerably increased, and in

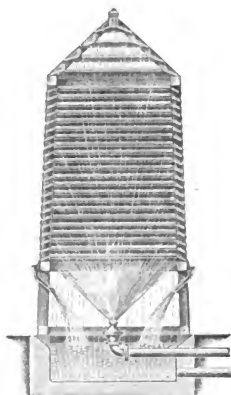


FIG. 66.—
KÖRTZ'S COOLING TOWER.

this connection probably the table on page 453, Vol. I., may come in useful. By means of these cooling towers, water of any temperature may be cooled down to the temperature of the atmosphere, and even to 2 or 3 degrees below this.

Refrigeration. — When we desire to effect a reduction of temperature to below that of the surrounding atmosphere, we call it refrigeration, and this has become a fine art during the last two decades. In the past, refrigerating machines have, roughly speaking, been constructed on two distinct principles; one in which the cold expanded gas is absorbed in water, and is reintroduced into the system in solution, while in the second, the expanded gas, having done its work, is reintroduced into the system by means of a compression pump. The first system has so few adherents now that it would be a waste of time and space to enter upon a description of the principles upon which the operation is founded, or as to how the construction is carried out in practice, but a thorough understanding of the "compression system" is absolutely necessary. Moreover, the first system has been sufficiently described in connection with the Brothers' laboratory refrigerator, on page 72, Vol. I.

Refrigeration machinery, made on the compression system, may be of several different patterns, according to the liquid or vapour used therein. Theoretically, from a physical point of view, it is of no consequence what compressible vapours are employed; they may be ether, sulphur dioxide, ammonia, carbon dioxide, or a mixture of some of them, but the effect of employing the various media is shown in the size of the machinery—the compressor, the condensing coils, and the coils of the refrigerating tank. For a given weight of ice to be produced in a given time, a carbonic acid machine would be a very small affair compared with an ether machine, but the pressures employed are very great in the former case as compared with the latter. Again, the compressor of a sulphur dioxide machine is constructed of copper, and requires a considerable stream of water to keep it cool, while the corresponding part of an ammonia machine is made of cast-iron, and requires no cooling water.

The action of refrigeration machines working on the compression system is easily explained. The expenditure of a certain amount of mechanical power W results in a certain quantity of heat R being extracted from the refrigerator, and a certain quantity of heat C is transferred to the condenser.

A consideration of the action of the "Carnot" engine when it is reversed will easily prove that if such an engine work between the lower absolute temperature T_1 , and the higher absolute temperature T_2 , and if it receives at the lower temperature a quantity of heat H , which it gives away at the higher temperature, then a certain amount of mechanical work W is absorbed. And, further, if the compression and expansion of the medium be carried out adiabatically while the reception of the heat at the lower temperature T_1 and its delivery at the higher temperature T_2 respectively take place isothermally, no other engine working between the same temperatures T_1 and T_2 , and carrying the heat H from the former to the latter level

of temperature, is able to perform this process with a smaller expenditure of mechanical work W . That is to say, in a theoretically perfect refrigerating machine, the working media must carry out exactly the reversed process of Carnot's heat engine, provided the extraction of heat takes place at the lower constant temperature T_i . It is further evident that for such a machine, according to the law of the conservation of energy, the relation exists :—

$$C = R + AW,$$

A , being the mechanical equivalent of heat ; W , the mechanical work expended ; R , the number of heat units extracted from the refrigerator, and C , the number of heat units put into the condenser. Moreover, in consequence of the reversible cycle of operations performed by the working medium, as this latter is in exactly the same state after having completed the four operations (adiabatic compression, isothermal compression, adiabatic expansion, isothermal expansion) as it was at the commencement, the second law of thermo-dynamics must be fulfilled, and consequently the relation holds good :—

$$\frac{R}{C} = \frac{T_i}{T_a}, \text{ or } C = R \frac{T_a}{T_i}.$$

Setting the two preceding values for C , equal to one another, it follows :—

$$R + AW = R \frac{T_a}{T_i}, \text{ or}$$

$$AW = \frac{T_a - T_i}{T_i} R,$$

or, the efficiency of the perfect refrigerating machine, working between the absolute temperature T_i and T_a , is :—

$$\frac{R}{AW} = \frac{T_i}{T_a - T_i}.$$

As the only condition in the establishment of this efficiency consists in the operations taking place according to Carnot's reversed cycle, it follows that the above value for $R \div AW$ applies to all machines so working, irrespective of the nature of the medium employed, whether that medium be ether, sulphur dioxide, ammonia, or carbonic acid.

In the foregoing general formula for the efficiency of refrigerating machines there are some interesting explanations for what sometimes occurs in extreme cases. Supposing the T_a and T_i to approach each other more and more, the value of $\frac{R}{AW}$ will gradually increase, and when $T_i = T_a$

then $\frac{R}{AW}$ is immensely great ; *i.e.*, with a very little mechanical work, an immense amount of refrigeration may take place, if the liquid to be cooled had only to be refrigerated for an infinitely small amount.

It is also possible that T_i may become greater than T_a . For instance, if brine at 25°C. were allowed to flow back into the refrigerator and the cooling water ran away at 20°C. , then the compressor *would be driven*,

if it were arranged as a motor, $\frac{R}{AW}$ becoming negative, but actually, the pump would have to work for the purpose of merely circulating the ammonia, the pressure in the refrigerator and condenser being exactly the same, but condensation going on in the condenser, and evaporation in the refrigerator as ordinarily. The student will find that there is a good deal to be obtained from this formula.

The *actual* efficiency of a refrigerating machine is always less than the theoretical efficiency, but will approach the maximum value more closely the smaller the difference between the higher and lower temperatures can be kept, and the importance of this rule must be observed in the design of such machines. In practice it means that the surfaces of condensers and refrigerators must be as extended as possible, that the liquids in contact with these surfaces must be kept in circulation to promote the transmission of heat, and that all refrigerating work must be performed without the production of ice. Further, the heat of compression must not be allowed to raise the temperature of the medium appreciably above the condensing temperature, and the size of the compression pump must be kept as small as possible to reduce friction—that is to say, liquids of high latent heat are preferable to those of lower degree on this account.

The bulk of the refrigeration operations of the world are to-day carried on by the compression of ammonia gas or of carbon dioxide, the former working at pressures from two atmospheres to 10 atmospheres, while the pressures of the latter system are 30 atmospheres to 75 atmospheres. A machine, which the author had at one time under his control, was of the Linde pattern, in which ammonia is the medium employed within the closed cycle; it was a No. 4 machine capable of producing six tons of ice per 24 hours, or of a cooling power (not making ice) equal to 10 tons per 24 hours. In this machine, the joints between the ends of the wrought-iron piping and the flanges were all carefully tinned and soldered over with pure tin, the joints between two flanges being made with the thinnest sheet rubber obtainable. The gland and stuffing box of the compressor piston was very long and of peculiar construction, and it acted so perfectly that even during hot weather, when the pressure had risen to 12 atmospheres owing to the warmth of the cooling water in the condenser, there was only the faintest odour of ammonia in the engine room. As a matter of fact, the loss of ammonia, in the author's experience, amounted to only £3. 10s. during the manufacture of 1,800 tons of ice. In the Linde system the compressing cylinder works perfectly cold, without requiring any water jacket, and is sometimes partially covered with frost when working at low brine temperatures.

If we refer to Fig. 67, we shall be able to understand more clearly the working of compression machines, and in the explanation that follows ammonia will be taken as the medium for compression and expansion.

To start with, the apparatus is charged with nearly anhydrous ammonia. The pump *A* receives the expanded vapour from the refrigerator coils *C* and compresses it into the coils of the condenser *B*, in which the

vapour is liquefied, and from whence it escapes into the refrigerator by means of the regulating cock *D*. It again evaporates in the refrigerator, cooling the brine solution, or the solution of chloride of calcium placed therein, to many degrees below the freezing point of water, and this cold brine is circulated in such apparatus as requires to be cooled. This cycle of operations is continually going on, the vapour being condensed and liquefied in the condenser, and re-evaporated in the refrigerator, where it is cooling the liquid that surrounds the coils.

The formula already given ($C = R + AW$) shows that the heat units *C* put into the condenser equal that number extracted from the refrigerator + the heat produced by the mechanical work of the compressor. This heat has to be absorbed and carried away by the cooling water, therefore it is necessary to have *W* as small as possible. It is in this direction that the properties of vapour density, vapour tension, and latent heat come to be important considerations, as these properties decide the size and capacity of compressor and engine, in order that a certain quantity of work may be

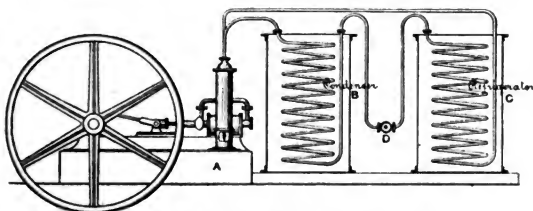


FIG. 67.—AMMONIA COMPRESSION REFRIGERATOR.

done in a given time. The following table will show the properties of the principal substances used in refrigerating machines.

TABLE 15.

IN WHICH ALL NUMBERS ARE BASED ON THE METRIC SYSTEM.

Substance	Vapour Density.	Weight in grms of 1 litre.	Latent Heat of Vapour.	Vapour Tensions, mm.			Boiling Point of Liquid.	Specific Heats. Equal Weights. Water = 1
				At -20°C.	At 0°C.	At +20°C.		
Ether	2.556	3.314	91	67.5	183.3	433.3	34.2°	.4810
SO ₂	2.247	2.860	92	479.5	1165.1	2462.0	-10.5°	.1544
Air	1.000	1.293	—	—	—	—	—	.2374
Water	0.621	0.806	537	0.927	4.6	17.391	100°	1.0000*
Ammonia	0.589	0.769	314	1397.7	3162.9	6467.0	-33.7°	1.2287
Carb. acid	1.529	1.977	139†	15150	27000	44700	-78°	.2169

* Dry steam = 0.475 under constant pressure. † Total latent heat. The latent heat of carbonic acid is 79.23 at -25°C.; 57.48 at 0°C.; 31.80 at 22°C.; and 3.72 at 30.8°C.

A careful consideration of the table shows us very clearly that ammonia is the most convenient agent to employ in any refrigeration system working by compression. Air is included in the list, as "cold air" refrigerating machines have been, and still are, in the market, being recommended by some on the supposed advantage that "no chemicals are required." But cold air machines require very large compressing cylinders, and, as the pistons must be perfectly air-tight, the power W in the formula must certainly be higher than that required for ammonia compression, in consequence. Moreover, cold air machines have to work with a very low T_i and high T_k , — usually T_i is -30°C. and T_k is $+70^\circ \text{C.}$

When refrigerating machines are employed for cooling purposes, cold brine or calcium chloride solution is usually circulated in pipes immersed in the liquid to be cooled, and it is advisable to circulate as large a quantity as possible, in order to ensure efficiency. This is also the case in the manufacture of solid blocks of ice, as will be seen from the following observation. During a period of ice-making—the block-ice being produced in moulds 6.5 inches square and three feet deep—the blocks, weighing about $\frac{1}{2}$ -cwt., took about 18 hours to freeze solid when the brine was kept at -8°C. to -6°C. by rapid circulation; but with deficient circulation in which the brine entered at -16°C. and left at -2°C. the moulds would take 24 hours to freeze. Ice produced in an ordinary refrigerator is opaque, owing to the air enclosed within it. Bubbles of air are mechanically squeezed out near the side of the mould, and they attach themselves to the advancing ice in such a manner as to leave a capillary tube running from the outside to the very centre of the mould. Agitation during the freezing process will eliminate this air and produce clear ice.

As to the cost of cooling by the aid of compression refrigerating machines, it should be remembered that it is not economical to first produce ice and then to use it for cooling purposes. The question of the latent heat of fusion comes in here, so that a machine that will make six tons of solid ice per day will do cooling equal to the making of 10 tons of ice, the latent heat of fusion of ice being 79 C.H. units for each pound, as already stated.

The Linde machine just mentioned was composed of a No. 4 compressor, united to No. 5 condenser and refrigerator, so as to bring the T_k and T_i as near to each other as possible. The engine driving the compressor and pumps had a steam cylinder 12 inches in diameter with a 24 inch stroke, cutting off at one half, and capable of exerting 19 I.H.P. When 1,250 gallons of cooling water per hour were supplied at 10°C. the actual consumption of motive power was 10 B.H.P., but in summer, when the temperature of the cooling water ran up to 21°C. , 13.5 B.H.P. was requisite; say an average of 12 B.H.P.

Many careful trials were made with this machine, the results of which may be given as follows:—

By the contract (which was carried out by Messrs. Sölzer Brothers, of Winterthur) the machine was to be capable of cooling 850 gallons of brine (1.07 sp. gr.) per hour from 10°C. to 2°C. ; it actually cooled 1,350 gallons per hour between these temperatures. It also cooled 1,700 gallons per hour from 18°C. to 8°C. In the first instance, the C.H. units abstracted

per hour amount to 108,000, or equal to 14 tons of ice daily, and in the latter case to 170,000 units per hour, or 21 tons of ice daily.

One very great development of the use of refrigerating machines lies in the direction of cold storage. Cold stores are now to be found in almost every large town in this country, and also abroad, while our steamers are fitted with the most efficient refrigerating plant to ensure the safe carriage of perishable cargoes. The subject possesses its own technology, so that details can scarcely be given in a work of this kind. Each material stored or carried requires a specific temperature to keep it fit for the market, though they do not differ between very wide limits; thus, while apples require to be kept at 1° C., bananas require 2° C., butter 2° C., oranges 3° C., in short, vegetable produce requires to be kept just above the freezing point of water, and the same is true of meat and animal products generally. Wines, honey, flour, beer are usually allowed a little more warmth, say, to 4° C.

In the case of general refrigeration, it is not only necessary to maintain a constant temperature, throughout the chill room, but to keep the humidity constant also. This is brought about by the continual circulation of cooled air. The air of the room, that has become heated by contact with the goods, and with the floor, ceiling, and walls, is withdrawn by means of a fan and cooled down in a special cooling chamber, until there is sufficient difference between this cooled air and that of the chill room, into which it is again passed. During the operation of cooling, moisture is deposited in the shape of snow, which, of course, has to be removed from time to time. The volume of air to be circulated, and also the degree of refrigeration, must of necessity be furnished by practical experience, but enough has already been said to enable both these factors to be calculated, when the variable factor is made known. The question of the humidity may also be found explained in the chapter dealing with evaporation and distillation.

In Chapter IV. it is shown how air fully saturated with aqueous vapour may be practically dried by warming it, even though no moisture be lost; here we have the opposite effect, or a condition in which partly saturated air becomes supersaturated by cooling, and as the excess of moisture is deposited in the snow chambers, a drying process is still actually proceeding at a low temperature.

It is doubtful whether refrigerating machines have undergone much real improvement during the past two decades, but if it should be argued that they have, it would be good practice to compare the results of their trials with the results obtained by a committee of engineers on a Linde machine at the Munich Ice Works in 1884. These results are not generally accessible, and therefore they will be given in full from the Report of the Committee.

The Munich Ice Works were fitted with two ammonia compressors corresponding to the production of 24 tons of ice per 24 hours. They were driven by a turbine acting directly upon the main shaft, and by a horizontal condensing steam engine with Sülzer valve gear, which drove a counter shaft and from thence down to the compressor pulley, which was common to both machines. The ammonia condenser was constructed to serve for an ordinary 48-ton machine, as also was the ice-tank, which was

divided into three longitudinal divisions. The condenser was placed in the stream driving the turbine. The ice was formed in blocks weighing $\frac{1}{2}$ -cwt. each, and the lifting and travelling of the moulds was effected by an overhead traveller driven by a high-speed rope.

For the purposes of the trial, the turbine and one of the compressors was disconnected from the main shaft, leaving the steam engine to supply the power necessary to drive one 24 ton compressor, working into a 48 ton condenser, and into a 48 ton ice tank. It also had to drive the travelling crane, the brine circulators, the agitators in the ice-moulds, the pump for freezing-water, and the pump delivering warm water into the thawing vessel. The diameter of the steam pipe between the engine and boiler was 204 feet in length and 4 inches in diameter, of which 123 feet was out in the open air. The duration of the trial was 36 hours, from which the following particulars were recorded:—

Steam engine :

Diameter of cylinder	14.5	inches
Stroke of piston	31.5	"
Diameter of piston rod	2.18	"

Ammonia compressor—Double-acting :

Diameter of cylinder	12.8	inches
Stroke of piston	21.3	"
Diameter of piston rod	2.55	"

Mean values from steam engine :

Revolutions per minute	68.7	
Indicated mean pressure, front.....	30.29	lbs.
Do. do. do. back.....	28.01	"
Indicated horse-power	52.53	
Pressure in steam pipe	76.36	lbs.
Vacuum in inches of mercury	22.6	inches
Water condensed from steam pipes ...	2,419	lbs.
Total quantity of feed-water	40,130	"
Total feed-water put into boilers	40,130	"
Condensed from steam pipes	2,419	"

Steam consumed by steam engine	37,711	lbs.
--------------------------------------	--------	------

Consumption of steam per I.H.P. hour :

(a) Subtracting condensed water	19.36	lbs.
(b) Including condensed water	21.22	"

Consumption of fuel per I.H.P. hour :

(a) =	2.42	lbs.
(b) =	2.65	lbs.

Power consumed in driving :

(a) Entire ice factory	52.53	I.H.P.
(b) Ammonia compressor alone	38.40	"
(c) Shafting and all auxiliary apparatus .	7.10	"
(d) Counter shaft and compressor shaft .	1.70	"

Assuming an efficiency of 95% for the compressor, the amount of compression work would be 36.6 H.P. corresponding to :—

$$AW = \frac{36.6 \times 550 \times 3,600}{1,390} = 52,135 \text{ C.H.U. per hour.}$$

Ammonia compressor :

Revolutions per minute	64.8
Ammonia pressure in refrigerator	25.3 lbs.
Do. do. in condenser	85.5 „
Temperature of ammonia in refrigerator	—24° C.
Do. do. in condenser ..	13° C.

Ice tanks :

Temperature of brine	—4° C.
Freezing time for each block	30 hours
Ice discharged per hour	3,659 lbs.
Ice per lb. of feed-water	3.28 „
Ice produced per lb. of fuel	26.34 „

From the foregoing figures the actual efficiency of the machine may be compared with the theoretical efficiency. Reckoning 110 C.H. units as being necessarily extracted from every lb. of water from the time of its being filled into the moulds until it is discharged as ice (including the losses in thawing the ice from the moulds previous to discharging it), the actual duty in the refrigerator amounted per hour to :—

$$R' = 110 \times 3,659 = 402,490 \text{ C.H. units,}$$

and the condenser duty was consequently :—

$$C = R + AW = 454,625 \text{ C.H. units per hour.}$$

The actual efficiency of the ice machine was therefore :—

$$\frac{R'}{AW} = \frac{402,490}{52,135} = 7.72$$

whilst for a perfect machine, with the working substance acting between the lower temperature —10° C. and the higher temperature 14°C., the theoretical efficiency is :—

$$\frac{R}{AW} = \frac{273 - 10}{(273 + 14) - (273 - 10)} = 11.0$$

Comparing the number of heat units B put into the steam boiler (which covered the work for all the auxiliary appliances in the factory) with those found in the refrigerator, it results that as one pound of steam at 76 lbs. pressure produced 3.28 lbs. of ice, the generation of one pound of steam requiring 655 C.H. units and the formation of one pound of ice corresponding to 110 C.H. units, the ratio is :—

$$\frac{R'}{B} = \frac{360}{655} = \frac{1}{1.8} = 0.55$$

which is by far the most economical figure hitherto published from an independent and carefully conducted trial, to which, however, it should be pointed out, the large surfaces of the refrigerator and condenser, and the low temperature and the large volume of cooling water available, materially contributed.

In a small machine, one ton of coal will make 10 tons of ice. Larger machines are more economical, and as it is simply a question of power, all depends upon whether that power has been economically raised and applied. It is of no use to blame the ice machine for any shortcomings when the steam boilers are antiquated or badly worked, or the steam engine a regular waster for steam; still, these things are chronicled in the books of rule of thumb.

If we follow the rule given on page 305, of Vol. I., and allow one penny per B.H.P. per hour as the cost of running small steam engines situated at a distance from the steam boilers, the 12 B.H.P. used in Linde No. 4 machine will cost 24s. for the 24 hours. For the same period, the wages will amount to at least 12s.; oils and other sundries to another 1s., while repairs, interest on capital, and depreciation will run away with 10s. more. The question of cooling water must depend on local circumstances—it may cost nothing in some situations, while in others it may cost as much as 30s. per day, or 5s. per ton of ice, or, if ice be not made, the machine being used simply for cooling the water used in the condenser, may cost from nothing to 3s. per ton of ice equivalent. It will be safe to reckon on 5,000 gallons of cooling water to the ton of ice, or 3,000 gallons per ton of ice equivalent. Without reckoning anything for cooling water, the daily expenditure will amount to not less than 47s., so that we are able to abstract 4,000 C.H. units by means of a small ammonia-compressing refrigerator for one penny, or, in other words, we can cool about two tons of water 1° C. for the same amount. One brake-horse-power will extract 10,000 C.H. units per hour in small machines, while in refrigerators of large size considerably better results can be obtained.

It has already been shown how the actual process of freezing water may be delayed by a defective circulation of the refrigerant. It must also be noted that the thicker the layer of water to be frozen the longer does the actual process of freezing take; not, however, in simple arithmetical proportion, as blocks 7 inches by 3 inches wide will freeze in 8 hours with the cold brine at -8° C., while if the blocks be 7 inches square, they will not freeze in less than 18 hours and even longer than this if there be a large temperature difference, between the brine entering and leaving. As the thickness of the block increases, the time required becomes very high, and this is why the manufacturer of ice prefers to make thin blocks. While blocks seven inches in thickness take 18 hours to freeze, those ten inches thick will require 45 hours, and twelve inches in thickness will scarcely be ready to lift in less than 70 hours. When the cold has to be applied at a distance from the machine, heat is first extracted from a fairly strong brine, or from a solution of chloride of calcium, and this is circulated through a system of pipes, if rooms or chambers have to be cooled, or solutions cooled in tanks, but in the manufacture of ice the refrigerant is circulated in tanks into which the pure water cans are dipped. Chloride of calcium solution is a more convenient liquid for use in these operations than brine, and from the annexed table it will be seen that the best strength to employ would be one containing 30.0 per cent. of calcium chloride, which possesses a specific gravity of 1.283, or 57° Tw., and does not freeze before -48° C.

TABLE 18.

SOLUTIONS OF CHLORIDE OF CALCIUM.

Sp. gr. at 18° C.	% Ca Cl ₂ .	Freezing Point °C.	Sp. gr. at 18° C.	% Ca Cl ₂ .	Freezing Point °C.
1·507	50	29·3°	1·240	26	—32·8°
1·485	48	28·4°	1·219	24	—27·3°
1·462	46	26·2°	1·200	22	—22·6°
1·440	44	22·7°	1·179	20	—18·6°
1·418	42	17·6°	1·159	18	—15·2°
1·395	40	10·9°	1·140	16	—12·2°
1·373	38	+ 1·5°	1·121	14	—9·8°
1·349	36	—9·8°	1·103	12	—7·7°
1·327	34	—23·3°	1·085	10	—5·0°
1·305	32	—39·6°	1·067	8	—4·3°
1·283	30	—48·0°	1·050	6	—3·0°
1·261	28	—39·6°	1·032	4	—1·9°

When anyone is contemplating the erection of refrigerating machinery the utmost caution must be exercised in accepting published results of an advertising character. It may be that the results of trials are quite accurately described, so far as they go, but as a rule they do not go far enough, and do not describe the particular circumstances connected with each machine. It is useless to simply describe the type of machine as an ammonia machine, a sulphur dioxide machine, or a carbonic acid machine, and to say that they have each absorbed so many calories per hour, without at the same time giving full details as to the refrigerator surface, and how the refrigerated material has been employed. It has been already shown how the actual process of freezing may be delayed by a defective circulation of the refrigerant alone, and the influence the extent of surface of both condenser and refrigerator coils has upon the extraction of heat, so it is quite possible that a well designed sulphurous acid machine, or a similar apparatus working with carbonic acid, may give better results than a badly designed ammonia machine; this is not the fault of the system, but lies in the method of carrying it out in practice. An amusing instance of this character was recently given in the advertising columns of a monthly journal devoted to ice and cold storage, in which the makers of a machine on the carbonic acid system claim 100 per cent. efficiency for their refrigerator, letting sulphurous acid down at 37 per cent. and an ammonia machine at 60 per cent. Upon another page of the same journal a competitor informs his readers that the final results of comparative trials between the three types of machines were 100 per cent. for sulphurous acid, 94 per cent. for carbonic acid, and 69 per cent. for ammonia.

The cost of refrigeration has an important bearing upon many of our industries. Some very large refrigerating machines are installed in the aniline colour works on the Continent, and they are also in use in the Dutch marga-

rine factories, in distilleries, stearine works, gunpowder works, and sugar works. In the chemical industries proper they are also in use, and, in this country, are employed in the phenol industry, the manufacture of chlorate of soda, and the Scottish shale-oil works, while in Widnes a special plant was run for some time for separating mono-hydrated sulphuric acid from the ordinary commercial acid; a process now no longer in operation. Refrigeration is also employed to separate ammonium chloride from the liquors of the ammonia soda process, the fine crystals so produced being afterwards compressed into tablets.

Some years ago (1884) Mr. C. Ellis made a proposal to recover the sulphate of soda from the waste liquor of copper extracting by the wet method, by a process of refrigeration. He pointed out that to separate 2.5 lbs. of the crystal ($\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$) from a gallon by refrigeration would only consume about one-tenth of the quantity of heat that would be necessary for evaporation in the ordinary way. Twelve thousand gallons of the waste liquors would yield at this rate 14 tons of the crystal or about 6.3 tons of anhydrous sulphate of soda.

We have already seen that two tons of water can be cooled 1°C. for one penny, so that we may cool 32 gallons through 14°C. for the same amount, 14° being the difference between 18°C. and 4°C. , and therefore the cost of separating the 14 tons of crystals by refrigeration would be :—

$$\frac{12,000}{32 \times 14} = 27 \text{ pence per ton,}$$

to which must be added the costs and charges for collecting the crystals. This is not given as an illustration of a successful working process, but as an instance as to how one's ideas can be worked out at the desk before any practical work is undertaken.

Refrigerating machines are now as reliable and as easy to manage as ordinary steam engines; their uniform action in continuous day and night work has ceased to attract attention, so that we may say the difficulties of construction attending the use of liquids of such high tension as ammonia and carbonic acid have been completely overcome.

CHAPTER II.

SEPARATING SOLUBLES FROM INSOLUBLES.

It will at once be seen that under the heading of this chapter we shall have to deal with widely differing species of operations, and it may therefore be useful to at once indicate the classes into which it is proposed to group the problems that may present themselves.

In the first class, those cases may be considered in which the primary object is to effect the solution of any easily soluble material in an appropriate non-volatile medium. The second class would deal with the problem of dissolving such substances when associated with large proportions of insoluble matters. Into the third class may conveniently be gathered those cases of difficultly soluble substances which require an intensification of contact to promote solution; while in the fourth class, the operation of solvents, whose volatility demands distinctive provision in the shape of protective and recovery plant, will be dealt with.

It will be as well to remark at the outset that the terms soluble and insoluble can only be employed in a relative sense, and the operation of solution or extraction is a much more complicated problem than at first sight appears. It is well known, of course, that substances though soluble in one menstruum may be quite insoluble in others, but this is not the point towards which attention should be directed now. If we consider water as the solvent, it will be found that as it becomes charged with soluble matters, the solution so produced has a very decided selective action upon other soluble matters, and it is this property which is often brought into operation in many chemical processes. Perhaps the most noteworthy instance of this character is the action of hydrochloric acid gas upon a solution of common salt, as when strong brine is caused to absorb hydrochloric acid gas, nearly the whole of the sodium chloride is precipitated. Again, sodium chloride is nearly insoluble in a strong solution of sodium chlorate—in fact it is so sparingly soluble that the two salts may be separated on the large scale by applying this principle. Sodium chloride is also sparingly soluble in cold concentrated solutions of caustic soda, while it is very soluble in such solutions at high temperatures.

Sometimes the impurities existing in solutions increase the solubility of the principal product of the operation, while in other cases the solubility is decreased. To take an instance from the nitrate of soda industry. The raw *caliche*, containing about 65 per cent. of nitrate of soda and 24

per cent. of common salt, beside other matters, is boiled up with water to extract the nitrate of soda from it. One hundred gallons of water will dissolve about 880 lbs. of nitrate of soda at 20°C. , while if the water be first saturated with common salt it will only dissolve 520 lbs. of nitrate.

Gin and others have called attention to the behaviour of certain salts in solution at temperatures above 100°C. , and it is probable that in time the peculiarities pointed out may be utilised in the chemical manufactures. It appears that a solution of sulphate of iron (FeSO_4) saturated at 100°C. when heated under pressure to about 160°C. deposits nearly the whole of the ferrous salt; in fact, the ferrous salt is insoluble in water at that temperature. The fact that certain sulphates act in this manner is not new, as it has long been known that calcium sulphate is not so soluble in steam boilers working under high pressures as it is when working at lower pressures, but no industrial process has been founded upon this knowledge. With sulphate of iron, however, some use has already been made of the discovery. It has been found that sulphate of copper does not behave as does the sulphate of iron; it remains in solution at high pressures, and so Gin, in a paper read before the Berlin Congress of Applied Chemistry, 1903, proposed to produce copper sulphate by treating ores and mattes of copper so as to prepare a solution of the mixed sulphates of copper and iron, and, after concentration, to submit the solution to high pressure treatment, by which the iron sulphate would become insoluble. Such a process seems to open out many possibilities. But we must return to our classification.

The process of refining salt-cake will serve to illustrate the first class of operations. Here the sulphate of soda in the raw material is accompanied by various impurities—sulphate of iron, sulphate of alumina, and sulphate of lime, as well as the original insoluble matters, which are present owing to the general collection of foreign matter which must accompany any technical process. This operation represents very fairly a large class of manufacturing processes where the primary object is to dissolve a certain substance, which by the mere process of going into solution is separated from small quantities of insoluble impurities, or matters which, though soluble in the crude article, may be turned into insoluble matters, in order that they may be so separated. In refining salt-cake, we have to deal with a substance containing about 98 per cent. of soluble matter, and the chief point in designing plant would be to so arrange it that the solution of the substance should be made as expeditiously as possible, while at the same time it is requisite that some pre-determined specific gravity of the solution should be reached. This is virtually an operation of simple solution, but the next process to be described will differ in respect to those additional features which relegate it to the second class.

When we have to dissolve a substance from a mixture of solubles and insolubles, such as carbonate of soda from the black ash ball in the Leblanc caustic soda process, the operation is generally called *lixiviation*, and it is easy to see that such a process may be carried out in many ways. It has, however, become an established custom, where the solution is easily

effected, to place such substances upon the perforated false bottom of what is termed a lixiviating tank, and there treat it either with water or some other solvent by a progressive sequence of operations. In the ordinary black ash vat the process is carried on in a series generally of five or more vats, so that water may be turned upon the nearly spent black ash waste, gradually finding its way through the material in the vats in front of it, and so leaving the series in a very concentrated state. It will be seen that any process for dissolving out the soluble matter from a very large quantity of insoluble matter will be very cheaply effected by such a means as this, as the vats simply require filling with fresh matter, the spent waste being withdrawn when the soluble substances have been completely washed out. Black ash yields approximately half of its weight soluble, the other half being insoluble.

Another process which serves as a good illustration of the operation of lixiviation is that called the "vatting" process in wet copper extraction. The burned pyrites after having been roasted with salt contain the bulk of the copper in a soluble form, as a great deal of the sulphur has formed sulphuric acid and sulphate of soda, setting free hydrochloric acid, which acts upon the copper to form chloride. The process of lixiviating the calcined ore results in the extraction of the soluble iron salts, soluble soda salts, and the greater portion of the copper salts; but as oxide of copper is always present in the calcined ore, it is further necessary to wash it or lixivate it with water containing a fair quantity of hydrochloric acid. It will be seen that the introduction of an acid element is sufficient to change the method of construction of the apparatus in which the lixiviation is effected. In the case of black ash the solution is alkaline, and wrought iron plates may be used in the construction, as these are but little acted upon, except by the sulphide of sodium which is present as an impurity; but this action is very small. The lixiviating tanks of the wet copper extractor could not be made of iron on account of the strongly acid character of the liquors, and the action moreover that the soluble salts of copper would have upon iron, so that wooden tanks are employed for this industry, and these have to be constructed in a special manner.

Physical conditions sometimes play a very important part in lixiviation processes. In the Löwig caustic soda process, wherein carbonate of soda is heated to a high temperature with oxide of iron, there is formed a ferrite of soda, and during the lixiviation of this furnaced product the ferrite is decomposed, forming caustic soda and a finely precipitated hydrated oxide of iron. The presence of this hydrated oxide tends to make the lixiviation a slower and slower process, so that if special means were not taken to keep the material in the vats in a condition in which the liquid would percolate through them easily, the process would soon come to a standstill. These illustrations show us the differences that exist between the operations of solution and lixiviation.

The form of operation wherein difficultly soluble matters are separated from insoluble matters, finds illustration in the manufacturing of dyewood extracts. In several instances the soluble matters do not exceed several

parts per hundred, and as these extracted substances do not easily enter the fluid used for extraction, especially when water is employed, prolonged contact is essentially necessary to secure an economical result. In the manufacture of several dyewood extracts, the solution, as it leaves the extractor, does not average more than 1.01 specific gravity, and this weak solution has to be evaporated for sale to a specific gravity of 1.12. It is in relation to such processes as these that the term extraction is more generally employed. Here also we have to consider the influence of the materials of which the plant is constructed upon the quality of the finished article. In some cases the employment of iron is out of the question as it would colour the product, and therefore vessels of copper or of aluminium are extensively employed.

Our fourth class of operation may be illustrated from such processes as the extraction of oils from seeds, oils from dirty engine waste, etc., or the alkaloids from barks. In these cases water is not the usual solvent, its place being taken by liquids of a volatile nature specially suited to the object in view. It will thus be seen that there is a considerable difference between the operations of solution, lixiviation and extraction, and it will be well if we bear these sub-divisions in mind.

Two important points have to be taken into consideration when dealing with this subject, one of which is the physical state of the material from which the soluble matter is to be separated, the other has reference to the nature of the solvent. The first consideration, namely, the physical state of the material, is one of the utmost importance. It has been already noticed, on page 456, Vol. I., that the size of the particles of the mixture undergoing lixiviation determines to a great extent the ease with which such operations can be effected, and the limit of their duration. To some extent the chemical changes during the process also influence the ease with which the operations may be performed. If a hydrated precipitate is produced during the process, it is more than likely that it will act detrimentally, but if the particles can be kept granular, the operation will go on smoothly. The filtration of water through sand is an admirable illustration of this, for dirty river water, say from such a river as the Irwell, can be filtered through sand at a very rapid rate, until the upper layers of the sand become choked with the floating impurities originally present in the water, when the filtration stops. It is just the same with ordinary lixiviating vats. Again, in the extraction of oils from crushed seeds, large particles allow of the oils being easily extracted by the employment of suitable solvents, such as petroleum spirit, but the existence of the extremely fine particles is very detrimental to the free percolation of the solvent saturated with oil. With dyewood extracts there is not so much difficulty, but the amount of the solvent in this case, which is left amongst the residuum, calls for a little further treatment than in the ordinary process of lixiviation. In the case of simple solution, the physical state of the material is not of so much importance, as apparatus can be readily devised to keep the substances undergoing solution in constant contact with the liquids in which they are being dissolved, and it is a recognised

fact that in many cases the more finely divided these substances are, the more difficulty there is in dealing with them.

As to the nature of the solvents, it is quite evident that their chemical properties will influence in a very great degree the form and construction of the apparatus in which they are to be employed. With water there is no special care required; it is cheap, and it does not easily volatilise even at comparatively high temperatures. But with such liquids as ether, benzene, petroleum spirit, or bisulphide of carbon, it is otherwise. And here again the differences between such fluids must be noted. Petroleum spirit is lighter than water, and therefore floats upon its surface, while bisulphide of carbon is heavier than water and sinks below it. Substances which require alcohol for their extraction give us another problem to deal with, as, unlike petroleum spirit or bisulphide of carbon, which are insoluble in water, alcohol is soluble and must be kept entirely distinct from it. When the nature of the solvent is acid the construction of apparatus often gives the designer much trouble. Sulphuric acid, when diluted, can be used in lead-lined apparatus, and in some cases even in wooden tanks, but with nitric acid or hydrochloric acid the problem is often one of the very greatest difficulty. With such acids as acetic acid aluminium is coming much into use, and it may be possible some day to use alloys of various metals for the performance of many operations which are to-day considered impossible.

When we come to consider the effect of temperature, it will be found that this exercises a very great influence on the design and construction of plant. In dealing with water, it will of course be seen that temperatures up to 212° Fahrenheit can be easily applied. When it is necessary to go beyond this, as in the extraction of certain matters from dyewoods, the vessel must of course be closed, and this will be the case when operating with other solutions above the boiling point; but when a costly volatile solvent is employed in the place of water, no temperature approaching the boiling point by many degrees can be applied in open vessels, apart from general conditions of safety. As a rule, increase of temperature means increase of solubility, though with such substances as common salt this is not the case. Common salt does, in fact, dissolve in slightly larger quantities in hot than in cold water, but the difference is of no practical moment. On the other hand, although it does not dissolve to an appreciably greater extent in hot water than in cold water, yet the time occupied in solution is very much shortened as the temperature is increased, so that although in common parlance we may say that hot water does not increase the solubility of common salt, yet as a matter of practice the temperature has a considerable influence on the operation. As a rule, solubility increases with temperature in all other solvents as in water, but when we come to the more volatile class, not only do we have to provide for loss of the solvent at temperatures near the boiling point, which is an absolutely necessary proceeding, but we have to provide for the loss which takes place at ordinary temperatures, or to be more accurate, to provide measures for preventing such loss if contact with the air be permitted. But even where volatile

solvents are employed, more often than not the operation is made to take place at or near the boiling point, so that in this case a condenser must be provided for collecting the solvent that is vapourised, in order that it may come in for use over again.

The effect of temperature must be further carefully studied in connection with the manufacture of such products as dyewood extracts, as some of these are spoiled, so far as the market is concerned, by the application of an excess of heat, and as these extracts are mostly prepared in closed vessels, the products being heated with wet steam, the effect of pressure as well as temperature will have to be carefully studied. These are practical questions. No one outside these particular industries can enumerate all the ends that have to be carefully watched, but the knowledge that temperature will often introduce some disturbing element, will exhibit the finger-post of caution to those who wish to carry on a business scientifically.

The effect of pressure must also be carefully considered. When it is known that the influence of pressure is requisite to perfect some otherwise well defined operation, well known means at the designer's hands can be readily adapted for the construction of special apparatus, but he should know what are the reasons for any special line of procedure. In esparto-boiling, for instance, which used to be done in some works under the ordinary pressure of the atmosphere, the operation takes longer than when esparto is heated under pressure with the deglutinating material, and those who wish to effect as large a turn out of work as their neighbours in a plant of given size, always resort to pressure to hasten the operation. There are some substances, however, that refuse to dissolve in the solvent, unless pressure is applied simultaneously with the heat, or dissolve at such a slow rate as to make the manufacturing operation an exceedingly expensive one. No better illustration of this can be found than in the solution of water-glass or silicate of soda, produced by the fusion of soda ash and sand. This glass dissolves so slowly in water that the novice would believe it to be insoluble. At one time it was the custom to place the solid glass upon a perforated shelf in a dissolver and to turn steam into the vessel, the condensed liquid ultimately forming a strong solution, but to-day it has been found better to digest the glass in a closed vessel with water under the pressure of the steam employed, when after a more or less prolonged digestion, a solution of silicate of soda of 1.03 specific gravity is obtained. Rather than continue the operation in this manner, so as to procure a solution of higher density, it has been found cheaper to withdraw the liquor at the low density already named, and to concentrate it to the higher density required by means of multiple evaporation.

It must not be forgotten, however, that increase of pressure sometimes brings about decomposition, which digestion at the ordinary temperature and pressure fails to produce. We have an instance of this in the decomposition of manganese chloride by milk of chalk. If we digest a solution of manganese chloride with finely divided carbonate of lime under the ordinary temperature and pressure, no decomposition is brought about; in fact, the oxide of iron and alumina present in crude manganese liquors

are easily precipitated with limestone dust without any of the manganese being deposited. If, however, we heat a solution of manganese chloride with carbonate of lime, such as chalk, under a pressure equivalent to 40 lbs. of steam per square inch, chloride of calcium will be formed, which is soluble, and carbonate of manganese, which is insoluble. There are many other decompositions of a similar nature occurring in the daily round of manufacturing chemistry, so that the effect of pressure as well as temperature cannot be overlooked.

The designer of plant for operations such as we are now considering has first to ask himself the question whether it is the solution or the residuum that is required. In some cases both are wanted, as in the extraction of oils from seeds, where both the oil and the residuum are merchantable articles, and the operation is found coupled with some severe conditions. In the case just mentioned, the oil must be clear and free from any odour of the solvent employed, while the crushed seed residue must be dry so as to be easily made into feeding cakes. Another case of this kind has been already quoted, in which copper solution is washed out from calcined pyrites. Here the liquid containing the copper, and the spent ore, or "blue-billy" as it is called, are both required, and the condition is attached to the process that the spent ore shall not contain any appreciable quantity of copper. Another manufacture will furnish a third instance, wherein both fluid and solid substances are required—namely, the production of anthracene and green oil from coal tar distillates, but this example is an instance of an operation on the border line of this class of processes, and may fairly be treated as the result of crystallisation.

In some operations the solution only is wanted, as when soda ash is dissolved and made into solution for the production of crystals. The insoluble matter in this case is treated as a worthless residuum, and its disposal, as a rule, creates no difficulties. Then again, manganese liquors, after having been neutralised in the neutralising well, deposit upon repose the unrequired impurities, such as sulphate of lime and other substances. As a rule this residuum is bulky, and it entangles a certain amount of the soluble manganese, which must in some way or another be removed from it. Again, in causticising soda ash with lime, it is really only the solution of caustic soda that is required. It is quite true that means are taken in every works of this description to abstract the soda which is entangled with the carbonate of lime residuum, and that the carbonate of lime so freed from soda is used again in the furnacing process, but it is very doubtful whether there is any economy in employing it in preference to fresh limestone. This is not a matter of opinion, as can be demonstrated by the aid of information supplied in the foregoing pages. When it is known that the lime sludge residuum from the causticising operation contains at least 50 per cent. of water, and that a large proportion of it, being so finely divided, is carried by the draught from the furnace into the flues, necessitating frequent cleaning at great expense, and producing abnormal stoppages of the plant, it can soon be seen whether its recovery is worth the 4s. 8d. per ton paid for fresh limestone.

Of other cases in which the residue only is wanted, manganese mud is an example. The manganese is really the only valuable constituent, the soluble portion being chloride of calcium, which, more often than not, is run away to the nearest water course. In this instance, the presence of the solution of chloride of calcium entangled amongst the manganese mud is not of much detriment to the operation in which the mud is subsequently used, and therefore no severe attempt has ever been made to remove this quantity in practice. It would cost something to do this, even if it could be done successfully at any moderate cost. It is only fair to suppose that those in charge of the manganese process have weighed up the costs and advantages of getting a more concentrated magma for introduction into their stills.

The manufacture of Satinite is another instance of a process of this character, and the manufacture of such pigments as chromate of lead, Prussian blue, and similar substances, all fall under the same category. Satinite is produced by acting upon a solution of chloride of calcium with diluted sulphuric acid, whereby a hydrated sulphate of lime is produced, hydrochloric acid being liberated during the process. It is the residue here that is required, but every trace of the acid solution must be thoroughly washed away. And, similarly, in the manufacture of pigments, the colour itself must be thoroughly freed from all the soluble constituents which exist in the solution after the precipitation has been made.

A careful consideration of all the foregoing points must evidently be made before one can proceed to design plant for the practical carrying out of any of the operations illustrated, and it is here that the usefulness of a technical laboratory comes in. The specific gravity or the storage space will, in a great measure, decide the size of the plant, but, with this information, the time occupied by the process must be an element. And, further, in all such processes as these, a very large allowance must be made for irregularities. The author has seen lixiviating tanks for the extraction of soluble constituents from such substances as the spent oxide of iron from gasworks occupy a length of time for the operation four times exceeding the normal, and if the plant set apart for this work had not been ample, the stoppage of all other parts of the manufacture would have followed as a matter of course. The successful carrying out of any manufacture depends upon the arrangements made for contingencies. If such be not amply allowed for, it is quite easy to turn a process which might be peculiarly successful into one involving a considerable loss.

Dissolving Tanks.—We may now turn our attention to some methods of construction connected with the subject. The form of dissolver usually found in manufacturing establishments consists of a circular vessel, made of any suitable material, in which is placed a shaft (either vertical or horizontal, according to the shape of the vessel), and upon which are fixed what are called wings, arms, blades, or knives. These are sometimes placed flat against the circle of rotation, and in others they are inclined, so as to cut through the solution more easily. In some dissolvers of extended area, two or more shafts are placed within the vessel, and this

is a much better arrangement than one shaft with arms of long radius.

In vessels of large diameter (say the neutralising well in the manganese process of chlorine making), in which a diameter of 16 feet is often exceeded, any keen observer must have noticed how lazily the mass of liquid is swung round at about the same peripheral velocity as the revolving arms—truly a very inefficient way of producing agitation. A very general form may be seen in the upper vessel of Fig. 266 (page 508, Vol. I.) and this may be adopted for nearly all operations of this character. In some forms of dissolver the cage is made to occupy the whole surface of the dissolving vessel, the base of the cage being made removable for the purpose of cleaning, but it is seldom that so large a surface is needed. If the vessel is more than six feet in diameter, it would be better to fix two shafts, each fitted with arms, at distances from the periphery on either side equal to one-third of the diameter; the agitators would then be lighter, less cumbrous, and could be driven with greater velocity, with less tear and wear, and would produce a much more effective agitation than by the employment of a single shaft placed in the centre of the vessel. In some works, notably in the brewing and distilling industries, the agitating and rousing appliances are very complicated, but they do their work thoroughly.

The preceding remarks apply principally to what may be called vertical dissolvers, or simply open vessels, in which the agitators or stirrers work in an upright position. In solution tanks, the amount of agitation required is not excessive if the material be freely soluble, but, with difficultly soluble substances, the agitation must be energetic to keep the particles of undissolved material in suspension until the operation is completed. It is on this account that some engineers prefer the horizontal dissolver, which, in its simplest form, is an egg-ended boiler, through which runs a long horizontal shaft, to which the blades or stirring arms are attached, the ends of the shaft being passed through stuffing-boxes at either end of the vessel in order to prevent the liquid from escaping.

Both of the foregoing forms are, in the author's opinion, less effective than the Archimedean screw arrangement shown in Fig. 68, which has the

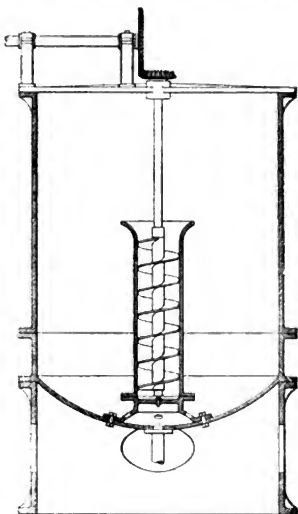


FIG. 68.—ARCHIMEDEAN SCREW AGITATOR.

advantage of bringing up the whole of the liquid from the bottom of the vessel and showering it over the top of the tube in which the screw is placed, while, if it is so desired, a reversal in the direction of rotation will take in the liquid at the top of the tube and force it through the lower end, when it cannot fail to thoroughly rouse any undissolved material that may have deposited there—in fact, it is a perfect agitator.

Whatever may be the disposition of the stirring or agitating arrangements, there are several other points quite as material to easy and successful working as any that could be brought under those heads. In dissolvers, there should be a cage for containing the material undergoing solution, and the construction of this must depend a great deal upon the nature of the material. A cage for containing quick-lime is made of half-inch round iron bars (sometimes of three-eighths only), while a cage for holding salt-cake, or carbonate of soda, undergoing solution is either made of steel wire netting, with one-quarter-inch mesh, or from quarter-inch sheet-iron, perforated with half-inch or three-eighths of an inch holes. In no case should the

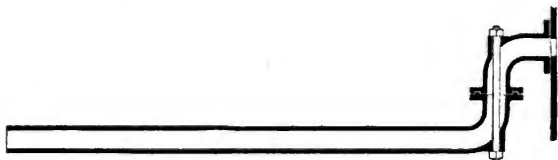


FIG. 69.—CAST SWIVEL PIPE FOR DECANTING LIQUIDS.

material be thrown into the depths of the dissolver, as, beside the splashing that would be dangerous to the workmen, most soluble substances are apt to form a solid cake when placed in contact with a small quantity of water, especially if they happen to be in a state of fine division, and this is very difficult to dissolve when lying still at the bottom of a vessel.

An outlet for the sediment and an outlet for the clear liquor must be provided, the former being placed at the lowest level whereat any residuum may collect, while the clear liquor outlet may be placed immediately above it, terminating in a swivel pipe placed inside the vessel. Some people run off the clear liquor from dissolving tanks by means of the old-fashioned syphon, but this is a dirty, clumsy, and wasteful process that should not be tolerated in any well-ordered establishment. The loose-leg or swivel pipe will allow of almost the last drop of clear liquor being decanted without disturbing the sediment. The ordinary cast-iron swivel pipe may be seen in Fig. 69, which shows it fitted to the side of a tank from which it is desired to draw off the clear liquor from the sediment below it. The two bends are kept together by the bolt, and as one flange contains a semicircular groove while the other is furnished with a projecting rib fitting loosely into it, it is not likely to be displaced when the loose-

eg is raised and lowered. Cast-iron loose-legs are made from 3 inches to 6 inches internal diameter, and when smaller sizes are required they are usually made from ordinary steam tubing, the loose-leg moving on a nipple screwed down in the machine to allow it to move easily. This form of swivel pipe is shown in Fig. 70.

One word may be said regarding the method of fixing the upright shaft in vertical agitators. If the ordinary plan be followed of sinking the lower end of the shaft in the footstep, this portion of the apparatus

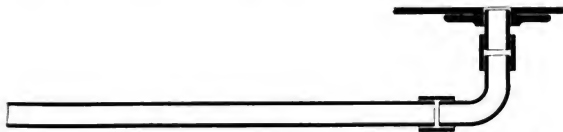


FIG. 70.—WROUGHT-IRON SWIVEL PIPE FOR DECANTING LIQUIDS.

will be often needing repair. Sand, and grit generally, will work into the footstep, and bed itself into the softer material of the combination, forming an excellent abrasive material. In order to avoid this, the recess in the step shown in Fig. 71 is fitted with a pivot piece, and upon this pivot the end of the shaft should rest. As the surfaces wear away, the pivot can be raised by packing pieces. As to the method of driving, the upper end of the agitator shaft may be surmounted by either a crown wheel or bevel gear, or friction cones, or the shaft may be belt-driven, but it is only in a few cases that belt-driving is permissible.

Dissolvers are also worked by air agitation, and these have the advantage of having no moving parts inside the vessel, and if the air supply is proportioned to the area of the vessel, the agitation will be ample. This proportion is about 250 cubic feet per square foot per hour. If a very violent agitation is required, 400 cubic feet per square foot per hour will supply it.

In many instances even air agitation is superfluous, as the circulation of the liquid is quite sufficient to effect all that is requisite.

Fig. 72 shows a tank fitted in this way. The steam that is employed to heat the solution is used in the form of an injector, and a circulating pipe draws the liquid from the bottom of the tank and delivers it over the top of the same into the cage containing the material for solution. The solution is thus heated by the steam during its passage through the circulating pipe, and becomes nearly saturated with the material during

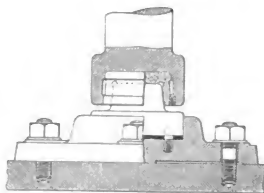


FIG. 71.—FOOTSTEP FOR AGITATOR SHAFT.

its passage through it. Even with low pressure steam this apparatus is very effective.

The nature of the operation called diffusion in beet-root sugar extraction may be found on page 159. When a similar operation is performed in open vessels it is called "Stage lixiviation," and instances may be found in the operation of extracting the soluble matters from black ash balls in the Leblanc process, the extraction of the soluble matters from burnt pyrites calcined with salt, or the extraction of soluble matters from the spent oxide of iron from gas works. When black ash balls are being treated, the apparatus is called a set of lixiviating vats, a sectional illustration of which may be seen in Figs. 73 and 74. The drawing (Fig. 73) shows a set of three vats in order to illustrate the principle upon which they are worked, but for nearly all purposes of lixiviation, a set of three only would never be contemplated. For another purpose, sets of three are employed, as will be shown in the chapter dealing with crystallisation, but the operation is not exactly the same as the one we are now considering.

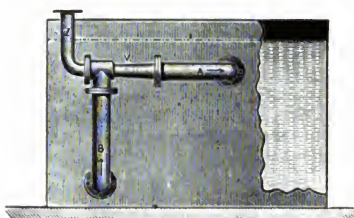


FIG. 72 —CIRCULATING DISSOLVER.

An end view of a lixiviating vat may be seen in Fig. 74, which is given to show the disposition of the running-off taps and the position of the circulating pipe at the back of the series. It will be noted that the liquor drawn off always comes from underneath the false-bottom, and when it is strong liquor, it is run from the top tap into the strong liquor shute, while

the weak liquor is run from the lower tap into the weak liquor shute, from which it finds its way into the weak-liquor well.

A set of five vats is the most rational number, but sets of four and six exist. When they are in operation, one vat is usually being filled and one being emptied of its insoluble matter, so that in sets of four, only two would often be working together, which is not sufficient. In working a set of five there would always be three in operation, sometimes four, but never more than four, as the weak vat would be draining its liquid contents outside the series of operations. Supposing the series to be in active work, we imagine them to be full of material in varying stages of exhaustion. The fifth vat would be filled ready for filling up with liquor from No. 4 so soon as the strength of that vat had fallen below that required for collection. By this time the residue in No. 4 would be about half spent and receiving liquor from No. 3, the residue in which would be about three-quarters spent. No. 3 would be receiving liquors from Nos. 2 and 1, water being run into the top of No. 1. By this time, however, it will have been noticed that the liquor running from the bottom of No. 1 into

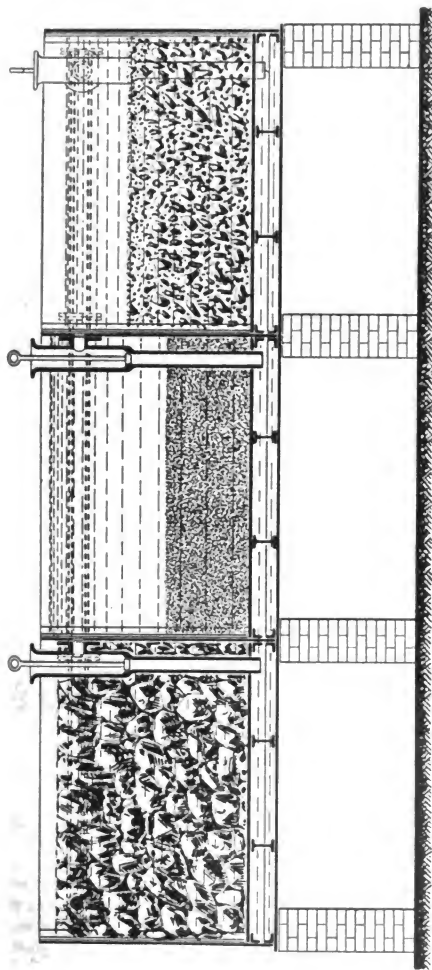


FIG. 73.—A SET OF THREE LIXIVIATING VATS.

No. 2 will have only a specific gravity of 1.005, so this tank (No. 1) is shut off from the series and the liquid that is in it allowed to drain off into a well, placed at a lower level, the draining continuing until the solid residuum is dry enough to cast out. Water is then turned upon No. 2, and No. 5 is connected with No. 4, and so on in continuation, one vat being drained, emptied and filled again with fresh material, and put into the series when another has been taken off. By examining the illustration it will be seen that the liquor, increasing its strength as it descends to the lower portion of the vat, passes through the false bottom on which the

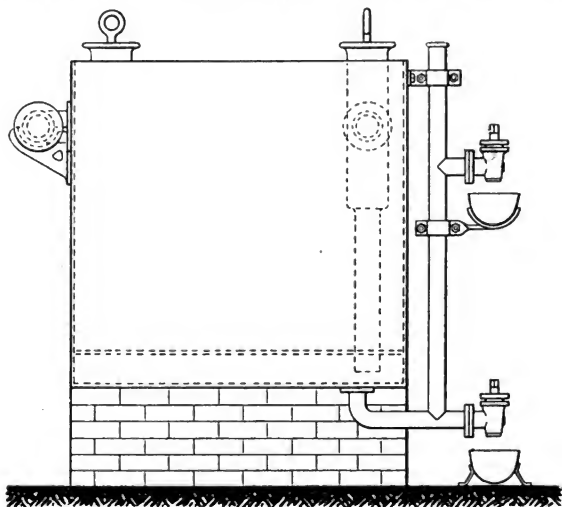


FIG. 74.—LIXIVIATING VATS. (End view.)

material is placed, and rising up the circulating pipe finds its way into the next stronger vat. It again travels downwards through the material and up the circulating pipe into the next vat, and so on until it reaches the outlet. It should be pointed out that the weak liquors or drainings from the spent vats are always used upon the next vat in the series before water is supplied, and in this way there should be no waste. When the lixiviating water is required warm, it should be heated before reaching the vat, and never by the simple introduction of a steam pipe, which only heats locally, and causes decomposition. The following table will show some particulars of the successive washings of various vats in the Leblanc black ash process.

TABLE 16.

SHOWING THE STRENGTH AND COMPOSITION OF THE LIQUORS FROM BLACK-ASH LIXIVIATING VATS, TAKEN SIMULTANEOUSLY. GRMS. PER LITRE.

Description.	°Tw.	°F.	Na ₂ S.	Total Na ₂ O.	Caustic Na ₂ O.
Running off strong vat	53	124	4.52	192.0	67.6
" 4 on to 5	26	104	2.58	94.2	40.0
" 3 on to 4	15	86	2.22	48.0	17.6
" 2 on to 3	7	86	2.58	23.5	7.5
" 1 to weak well ..	½	92	1.66	1.2	0.6

It will be seen that in connection with the working of lixiviating vats the Chemical Engineer has plenty of opportunity of exercising his skill. The material to be treated has to be brought up to the vats, raised and emptied into them, and when the lixiviation is complete and the residue is exhausted, the inert matter has to be removed from them and conveyed away, all of which operations may be performed mechanically at much less cost than by hand labour. The means at hand for such laborious work as this have already been fully described in Volume I. under the head of Moving Solids.

In this connection, a very interesting paper was read in November, 1903, before the Institution of Mining and Metallurgy by Mr. Chas. Butters, upon the handling of sand mechanically for cyanide vats, as practised at the Virginia City works, by means of the Blaisdell bottom-discharge excavator. It appears that this excavator, working in a tank 20 feet in diameter and from 3 ft. 6 ins. to 5 ft. deep, holding an 80 ton charge, discharges from 2.84 tons per H.P. hour at the commencement to 10.85 tons per horse-power hour at the finish. The daily working costs amount to 3s. 11d. for power, 11d. for supplies, tear and wear, and 2s. 6d. for labour, or in all seven-tenths of a penny per ton.

It will be noticed by following the foregoing description, that it is a *sine qua non*, that the insoluble residuum remaining in the vats should be porous, or at least open enough to allow of the passage of the necessary quantity of liquor in a given time. If a vat "sludges," as it is called, and becomes clayey in its character, it disturbs the whole set by preventing the free circulation of liquor, and this is one of those items not usually taken into consideration by the amateur in reckoning out costs, or in estimating yields. What becomes of the contents of sludged vats? Probably the waste heaps could tell us if they could speak.

It may be noted here that a set of six lixiviating vats, each measuring 12ft. x 8ft. x 4½ft., built up of three-eighths steel plates and all necessary appurtenances, will cost about £300., more or less, according to the state of the iron markets.

Sometimes the nature of the material to be treated, or the solvents employed, do not allow us to operate the process of stage lixiviation in

the way just described, and so the principle must be employed in another way. This is so in washing the spent oxide from gas works, or the calcined burned ore for wet copper extraction. In the first instance the material is often so slimy and clayey in its character that water would not flow through several vats of it, and in the second case the existence of so much finely divided matter would and does exercise a similar influence. When these substances are treated, it is usual to fill up the vat with the material and cover the contents either with water or the weaker liquors of a preceding operation, so that the soluble matters are as completely washed out as they would have been had the ordinary black ash process been followed. The spent oxide tanks will bear three or four washings in this manner before they become impervious to more water, while it is not an uncommon thing for the contents of copper lixiviating tanks to receive ten or twelve washings, each washing of course becoming weaker, until the last is but little stronger than pure water. To enable this to be done properly a sufficient number of vats must be employed, and it is chiefly in this direction that improvement should be looked for. Years ago, it was often the case that a manufacturer expected to recover as much copper from the ore when he had only tanks enough for six washings, as if he had sufficient for ten washings, and the chemist or the manager, or the foreman was frequently held to blame, while the fault lay with the proprietor himself. In dealing with copper liquors, timber, of which the vats are generally constructed, does not lend itself well to building on exactly the same methods employed for black ash vats, and as the liquor is required very hot it is lifted from one vat to another by means of a steam injector, either of hard lead or earthenware. Thus the liquors from underneath the false bottom of No. 1 tank would be drawn up and showered over No. 2, and from No. 2 to No. 3, and so on. By this means there should be no weak liquors to deal with separately, as was the case years ago, but all the liquors would be made to pass through the strong or last vat, which should at least be left at 50° Tw. or a sp. gr. of 1.25. In this way all the liquors get treated for silver, which is not the case when weak liquors are produced and used independently.

Extractors. — We may now pass on to that class of apparatus more generally known as extractors. There is no need to make more than two divisions; the first of which may be generally illustrated by the dyewood extractor, while the second is that form wherein oils are extracted from seeds, by means of volatile solvents as petroleum, ether, or bisulphide of carbon. In the first division there are many patterns in use, but the open tank, seldom seen nowadays, needs no description. The closed extractor that can be used for all pressures, all temperatures, and all solvents, may be seen in Fig. 75, but we need only consider its working in connection with the manufacture of aqueous extracts.

The body of the extractor is nearly filled with the raspings or chips of the dye-wood or other material from which it is proposed to manufacture the extract, and a certain quantity of water or weaker solution from a previous extraction is introduced. When steam is turned on,

the finely divided dyewood is continually being submitted to the hot liquor by means of which the soluble constituents are dissolved out. In some forms of extractor the steam is made to raise the liquid from the bottom of the extractor by means of a steam injector, on the same principle as is shown in Fig. 72, and this is also the plan followed in the "bowking" kiers of the bleacher, where grey-cloth is submitted to the cleansing action of a solution of soda ash.

In many large establishments extractors are worked in series, so that hot water is introduced into the vessel at one end of the series and leaves the last vessel as a concentrated solution of the extract. The process of extracting sugar from beet root, known as the "diffusion" process, is of this class. Instead of pulping the root, it is cut into thin slices averaging about one millimeter in thickness, and these are placed in an extractor or diffusion vessel, arranged sometimes in a series of ten. There is a heater to each extractor, by means of which the temperature of the solution is regulated, and when in action, warm water is run in at one end of the series and leaves the last vessel as a strong solution of sugar. Extractors may be made of cast iron, wrought iron-plates, copper, or aluminium, or they may be of cast or wrought iron, lined with thin sheet copper, lead, or aluminium, as occasion requires. Extractors that are worked under pressure should always be fitted with safety valves, and these should be examined and cleaned after each operation.

The next illustration (Fig. 76) shows quite a different form of extractor, which is employed with what are known as volatile solvents, such as petroleum spirit, benzol, or bisulphide of carbon. It is employed for such purposes as extracting oils from crushed seeds, the grease from dirty cotton waste, or the sulphur from the spent oxide of iron from gas works.

This form of extractor may be said to contain four principal parts: the extractor proper A, in which the substance is placed for dissolving out the soluble constituent from it; the condenser B, in which the volatilised

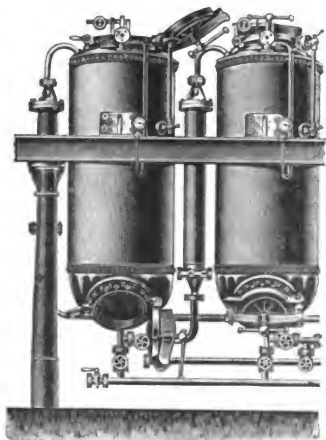


FIG. 75.—DYE-WOOD EXTRACTOR.

solvent is caught for use over again ; the reservoir R in which the condensed solvent is stored ; and the still C wherein the extracted matter in solution is deprived of the volatile solvent, and from whence it is delivered as a merchantable article. The illustration shows clearly enough what the range of operations must be. The oleaginous material (such as crushed cotton seed) is placed in the vessel A and treated with petroleum spirit, the solution being run through it into the still C where the spirit is boiled off, and having passed through the condenser B, flows into the reservoir

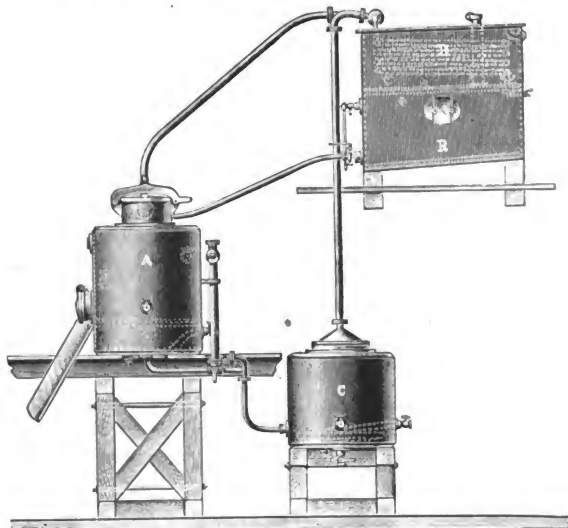


FIG. 76.—WEGELIN AND HÜBNER'S EXTRACTOR.

R. This is repeated several times until the residue in vessel A is free from oil, or rather until a sample of the spirit drawn from the test tap shows only a trace of oil. At this point the oil is in vessel C ; the greater portion of the spirit is in the reservoir R, but the residue in the vessel A is also completely saturated with it. This is now carefully driven off with steam, and the mixture of steam and spirit vapour condenses in the coils B and falls together into the reservoir R. Sometimes it is desirable to effect the heating with steam in a closed coil, and in such cases the design will require alteration, and in all patterns of this kind of apparatus, ample provision should be made for internal examination and for the cleaning out of the various parts.

We now can see what differences in construction are necessary when working with various volatile fluids. Petroleum spirit is lighter than water and floats upon its surface; bisulphide of carbon is heavier than water and forms a layer beneath it. In many cases, this property of bisulphide of carbon is a valuable one, as it can be kept under a layer of water without much evaporation taking place, but petroleum spirit, floating upon water, cannot be so protected. In using petroleum spirit in the apparatus shown in Fig. 72, the steam and vapour coming over at the end of the operation fall into the reservoir R wherein the water will collect at the bottom, while the spirit forms a layer above it. As the pipe for supplying the vessel A with solvent comes from the lower part of the vessel R, it is evident that if water occupied the space ranged by the pipe, it would run out into the extractor A, so that a draw-off cock must be placed at the lowest possible level in the vessel R to withdraw the water from time to time. A little reflection will now enable us to see that such an arrangement as this will not suffice when bisulphide of carbon is employed. This solvent is heavier than water, and when at the end of the operation the water and the vapour come out together, the liquid bisulphide will be deposited as the lower layer in the tank R while the water floats above it. This will not interfere at first with the use of the bisulphide, but as the water is an accumulating quantity it must be abstracted as regularly as it is formed, and for this purpose the water withdrawal tap must be placed about halfway up the reservoir R. Little points like these determine the workable character of any apparatus.

Settlers. — When a liquid is intermixed with insoluble particles, as when the insoluble matter of salt-cake is suspended within the fluid in which the sulphate of soda has been dissolved, or when manganese liquor has been neutralised, more often than not these insoluble particles have to be separated. There are several methods of doing this, but perhaps the most general way is by sedimentation or subsidence. The liquid is allowed to flow into large tanks where the suspended matters fall to the bottom and form a layer of greater or less thickness, entangling some of the solution amongst its particles.

It will be naturally asked whether the dimensions of the settling tanks have any influence upon the rate of settling. They have; but whether each insoluble substance has its own specific rate of settling, and this too in varying menstrea, the author cannot say, but it seems likely. The reader may be here referred to pages 498 and 503, Vol. I., dealing with the operation of elutriation and the fall of particles in water, but it will probably be found that there are many conditions that have not yet been investigated. In "blowing" an operation in the manganese recovery process, the settling of identical solutions is by no means similar—one "operation" may settle well, while the next settles badly, without any apparent change in the chemistry of the situation. Again, with such precipitates as Prussian blue, suspended in water or in the liquid in which it has been precipitated, there seems to be no certainty how it will behave when its subsidence is desired. In this direction the following table will be of use to the designer

as an aid if not an absolute guide. Four hundred gallons of manganese mud at 170°F., suspended in chloride of calcium solution of 24° Tw., were placed simultaneously in five vessels, two feet, three feet, four feet, five feet, and six feet diameter respectively, and the amount of settling noticed. The figures in the next table show the amount of clear liquor in gallons yielded by each in the given times recorded in the first column. The same liquid placed in a tall litre jar in the laboratory yielded in 24 hours 500 c.c. of clear solution.

TABLE 17.
SHOWING THE SETTLING IN VESSELS OF VARYING DIMENSIONS.

	2 ft.	3 ft.	4 ft.	5 ft.	6 ft.
Depth of original mud.	feet. 20	feet. 9	feet. 5	feet. 3'3	feet. 2'2
In 15 minutes	59	73	61	64	47
In 30 minutes	76	96	77	84	71
In 45 minutes	95	115	102	104	96
One hour	105	132	128	136	129
One hour, 15 minutes	112	144	144	152	140
One hour, 30 minutes	120	160	153	168	140
One hour, 45 minutes	128	162	164	172	
Two hours	132	168	169	176	
Two hours, 15 minutes	136	174	180	184	
Two hours, 45 minutes	148	185	184	184	
Three hours, 15 minutes	156	192	189		
Three hours, 45 minutes	160	194	189		
Four hours, 15 minutes	165	196			
Six hours	181	200			
Seven hours	186	200			
Eight hours	189				
Nine hours	194				
Ten hours	200				
Twelve hours	200				

It may be of interest here to state that a series of four subsidence tanks of three-eighths steel plate, each tank being 16ft. square by 7ft. deep, being one long tank with three partitions, so as to form four separate compartments, with cross stays and angle irons complete, and ready for filling, were built for £205, when steel plates were £5 15s. per ton. The labour alone cost £73, while the iron and rivets cost £117 15s.

Sedimentation—one can hardly call it subsidence—is made to operate in the treatment of sewage. After adding the precipitating materials, the sewage is made to flow through what are called precipitating tanks, mostly in constant flow. Here the suspended matters deposit while the more or less clear liquid flows away from the tank in a continuous stream. The action taking place in a tank of this kind depends to a great extent upon the velocity of flow of the stream, as well as the density and size of the particles of the suspended matters, and upon these details depends whether the effluent shall be clear or turbid.

We have now to deal with the residuum lying at the bottom of the tank, which, as we have already seen, has entangled more or less of the solution in which it has been precipitated. The problem is how to eliminate this soluble matter when it is required to do so.

The sediment lying in the tank will remain in much the same state as that in which it has been deposited, for very long periods, and the soluble matter may be extracted in several different ways. In the first, the batch may be diluted to a low density and allowed to settle again. This time the mud generally occupies a greater bulk than before dilution, but as it has been deposited in the presence of a weaker solution, it will contain less of the soluble ingredient than before. Still this takes much solvent, and though it is a common method of procedure it is not to be recommended, as we shall see later on. A second method is to dilute the mud with an equal bulk of water and allow the mixture to settle, and after withdrawing the clear liquor, to again dilute and settle, repeating this operation as many times as may be found necessary; but this occupies time. By this method one has still the same bulk of mud to deal with at the finish, but as the solution with which it is mixed is weak, it does not at first sight appear to be a sin to open the sludge gate and run it away to waste. This is where serious losses creep in.

Vacuum Filters. — The third method of dealing with the mud is to run it into a vacuum filter and first drain away all the liquid the pump will abstract, and then to apply wash waters sparingly until the bulk of the soluble constituents have been removed. The following experiments, performed for the purpose of testing the comparative value of these three methods, may now be found of interest here. Three litres of lime sludge settled from a causticising operation were diluted with water until the clear liquid marked 5° Tw. On allowing this to settle, 235 grammes of caustic alkali were collected in 6.25 litres of water. The second method just described was then used, viz., smaller successive dilutions, when 224 grammes were obtained in 4.47 litres of water, while when a smaller quantity viz., 3 litres, was treated on a vacuum filter as shown on page 61 of Vol. I., 250 grammes of caustic alkali were recovered in 3.45 litres of water. Although these figures were only obtained on a quantity of three litres, the numbers are quite accurate for large scale working, and show clearly the value of the vacuum filter. To take another instance. The neutralised liquor from the manganese chlorine process gave 75 per cent. of clear liquor by subsidence on the large scale; in the laboratory, settling in a tall litre jar, 76 per cent. was obtained; but on treating the sediment upon the vacuum filter, ten litres yielded 9.6 litres of clear liquor without the use of any wash water; while with washing up to 10.2 litres, practically the whole of the soluble manganese was extracted. Still another instance may be quoted, this time on a small laboratory filter pump, but the results can be equally well repeated on the large scale. Six cubic inches of the "bottoms" from chlorate of potash octagons were filtered by means of the vacuum pump, giving 5.5 cubic inches of pure liquor marking 29° Tw.; three cubic inches of water were then poured on to the filter and drained

off by the pump, producing three cubic inches of filtrate at 8° Tw.; three cubic inches more of water were again poured on and produced three cubic inches of filtrate at 1° Tw., showing that nearly the whole of the soluble matters had been extracted by the first washing. The mud left upon the filter was now shaken up with water and diluted to its original bulk (six cubic inches), when it oxidised 2.4 grains of protosulphate of iron. The six cubic inches of the original mud oxidised 1.035 grains of protosulphate, so that over 99 per cent. of the chlorate had been extracted in this very simple way.

Just a word may be said here of the laboratory method of determining the amount of settling that can be effected on the large scale, and to which reference has already been made on page 38, Vol. I. The method there described is accurate enough for all practical purposes; a litre of a finished

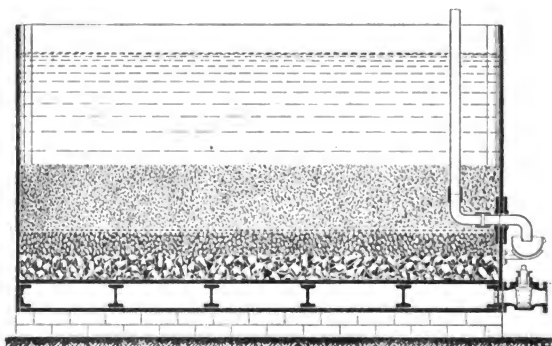


FIG. 77.—VACUUM FILTER.

chlorate octagon gave 768 c.c. of clear solution after 16 hours' settling, and 816 c.c. after 24 hours. On the large scale, the octagon was stopped at 5 a.m. and allowed to settle till 1 p.m., when there was 2.25 lineal feet of clear liquor and 0.75 lineal feet of mud. The recharging did not commence till a few hours after this, and at 4 p.m. the nine inches of mud had resolved itself into 6.5 inches of mud and 2.5 inches of clear liquor. This worked out would be 82 per cent. or 820 c.c. to the litre, which shows that it would have been better on the large scale to have allowed the settling to continue a few hours longer.

The construction of vacuum filters calls for no special comment, and if the drawing on page 53, Vol. I., be studied, no mistake can be possibly made in the construction of those of large size.

As a further illustration, however, of a special design, Fig. 77 shows a vacuum filter as fitted up for the filtration of the carbonate of lime from

causticising operations. A cast-iron or a wrought-iron vessel is fitted with perforated drainer-plates about six inches from the bottom, upon which is placed a layer of crushed limestone, of a size that will pass through an inch-and-a-half screen and yet be retained on one of three-quarters of an inch mesh. Upon this a layer of half-inch screenings is placed, six inches in thickness, from which all the dust has been taken out with a one-eighth-inch screen, and over all is placed a layer of steel wire netting of one-quarter of an inch mesh. As the netting cannot be obtained in one piece, it is the usual practice to cover the joints with old double-headed rails in order to keep it in its place, undisturbed by the shovels of the dischargers.

The illustration shows how such a filter is fitted up. On the right-hand side, within the tank, is a swivel pipe, made as already described on page 153, by means of which the clear liquor, from which the mud has been removed by subsidence, may be run off without having to pass through the body of the filter; a plan that considerably expedites the operation. A vacuum is applied to the tank from underneath the drainer plates. The vacuum pump is first connected to a cylindrical vessel so that a partial vacuum—about 25 inches of mercury—may be established within it; the filter is also connected from the main cock underneath the drainer plates to the same cylindrical vessel, and when the cock is opened it follows that the excess air and the drainings from the filter must find their way thereto. When there is more than one filter it is usual to run a main pipe along the whole row of them, and to connect each filter to this main by means of the cock shown in the walls of the draining space. This main is connected up to the cylindrical vessel. When this vessel is filled with liquid, air is first let in, and the liquid contents blown into overhead tanks by means of compressed air.

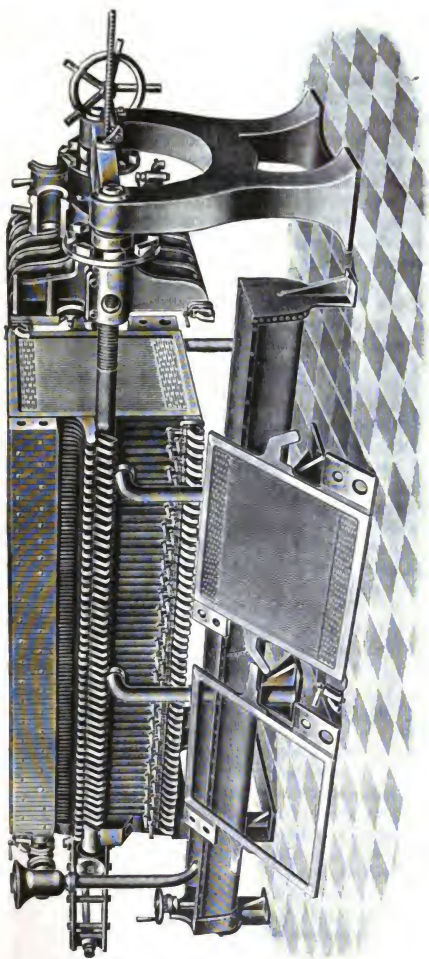
In order to secure the best results from vacuum filters of the foregoing pattern, they must be carefully handled. As a rule the old adage "more haste and less speed" is applicable in almost all cases. The best way of working is to run out the contents of the causticiser into the filters as soon as the causticising is finished when the contents are in a state of violent agitation, by which method the causticiser will seldom want cleaning out. The settling should take place in the filters, the clear liquor being removed by the swivel pipes, and while this settling is going on the coarser particles of the mud are finding their way to the wire netting, thus forming a good filtering medium. At a period, to be only found by experience, the vacuum pump should be started, and the clear liquor will find its way into the cylindrical vessel. When the mud is in a stiff condition owing to the removal of much of the water, it commences to crack all over the surface; but, just before this happens, the surface should be flooded with a few inches of hot water, and when this has disappeared, with a few inches more. In this way several washes with small quantities of water at each stage will do far more in removing the soluble matters than one or two large dilutions.

The stiff mud has now to be shovelled from the filter, by which method it is generally removed in this country, but in the large caustic-soda works

of the United States a somewhat different plan is adopted. The filtering tank is prepared in the usual way, and into it is fitted another, but perforated, tank, which is placed in position before the liquid mud is run into it. At the end of the filtering process, the inner perforated tank contains the hard mud, and it is picked up by an electric crane, carried off to the tip, emptied of its contents, and returned to the vacuum filter in so short a time as to be almost incredible. The filters may be made of any size, but for large operations, ten feet square (or circular) and five feet deep, with a space of six inches to eight inches under the false bottom, will be found a very convenient size.

The nature and construction of the filtering medium must be suited to the particular operation for which the filter is required. In filtering creosote for "Wells" oil, nothing is better than a layer of quarter-inch mesh steel wire netting, over which is laid ordinary cocoa-nut matting. For neutral and non-corrosive solutions, cheese-cloth, filter press cloth, or fine sacking may be made to replace the cocoa-nut matting, and provision must be made for occasional cleaning. For corrosive substances, such as sulphuric acid and caustic soda solutions, special materials must be employed; there is nothing better than crushed glass or sand for the former and crushed limestone for the latter, the limestone being carefully graded, the coarsest being placed in the lowest layer. At one time the sulphuric acid which was dearsenicated by passing sulphuretted hydrogen through it, was freed from the arsenious sulphide by mere subsidence, and it was found by experience that two days, or 48 hours, were required for the complete clarification to take place. Nearly all dearsenicated acid is now filtered, and of all materials that have been tried crushed glass bottles seem to answer best as the filtering medium. Old bottles crushed under edge runners are the most suitable, and when crushed the fragments should be sorted according to size and packed carefully into a lead-lined vessel, the larger pieces resting on a false bottom of perforated tiles and the smaller fragments filled in upon them.

Filter Presses. — It will be seen that the utmost pressure that could be placed upon a vacuum filter would be 29 inches of mercury. As a matter of fact the vacuum seldom exceeds 25 inches in practice. If the vessel were closed, however, the only limit to the effective pressure that could be placed on the surface of the material undergoing filtration would be the permeability and strength of the filtering medium, provided, of course, that the vessel be strong enough to sustain such a pressure. Filters of this kind are made, but they have not come into general use. There is a system, however, that has been wonderfully developed during the past thirty years, whereby considerable pressures have been utilised in the operation of filtration, viz., the system of "filter pressing." Very few works are now without a filter press, although many of them are not upon the best principle. The construction of the ordinary filter press of the best construction may be seen in the accompanying illustration, which shows one of Dehne's presses with absolute extraction. The press plates themselves are made to slide along a pair of horizontal bars for opening



DEHNE'S FILTER-PRESS, WITH ABSOLUTE EXTRACTION.

and closing the press, the latter operation being finished by tightening up the plates with the large screw at the end of the press. The press-cloths are placed between the plates of the press in a variety of ways, which perhaps it would be superfluous to describe, as any particular method is better thoroughly explained by the makers, when the special circumstances arise. The press being fitted with cloths, the magma requiring filtration is pumped into it by means of an ordinary steam pump, which, according to the author's experience, works best for this purpose when fitted with ball valves (Fig. 186, page 415, Vol. I.). The inlet at the press head is fitted with a pressure gauge so that the attendant may ensure that the full working pressure has been applied. The pump presses the magma against the surfaces of the filter cloth, through which the liquid portion passes, leaving the insoluble residue as a cake more or less solid, lying between two press cloths. When the press has been pumped up to its full capacity or working pressure, the pump is stopped, the screw at the end of the press withdrawn so as to allow the plates to be pulled back, which, releasing the cakes, allows them to fall into the receptacle placed under the press to receive them. Some substances will not form solid cakes, so that presses of special pattern have to be provided for dealing with them.

With some substances there is great difficulty in producing a hard, solid cake, and even in getting a satisfactory filtration. The thickness of the cake has much to do with this, but not all, as the method of working some precipitates is an art in itself. The usual thickness of the cakes for most substances is one inch, but this will have to be reduced for very fine or slimy precipitates and may be considerably increased for those that are sandy or granular. The difficulty with finely divided precipitates is best illustrated, perhaps, by an attempt to filter-press a recently precipitated magma of Prussian blue, when, if the pump is worked too quickly at the outset, the finely divided matters are forced into the pores of the press-cloth, so effectively that the filtration is absolutely stopped. This is also the case with gelatinous substances, which require the addition of some granular material before the aqueous portion can be pressed out. Gold ores after cyaniding are now filter pressed, and as the material is of a very granular nature the cakes are made up to three inches in thickness with the best results.

Substances which are found difficult to filter should by no means be forced against the cloths by great pressure. In fact, the use of a pump to fill the press is in such cases detrimental. Liquids such as these should be pumped into an overhead tank and allowed to flow therefrom to the press, under a head of about 16 feet, by which means a clear filtrate is obtained and much more satisfactory cakes than could be obtained by heavy pressure with a pump. As a rule most liquids filter-press better while hot than in the cold state, but of course there are many occasions when it is a *sine qua non* that they should be pressed cold. With viscous liquids, such as glycerine, the liquid must be pressed hot, as the viscosity of cold glycerine is so great as to almost prohibit its passage through a press in any reasonable time.

The press cakes, made as before described, are still however saturated with the liquor from which they have been pressed. From ordinary aqueous solutions, press cakes will contain about 40 to 45 per cent. of water, which, of course, holds in solution its corresponding quantity of the soluble matters, which it is generally of interest to remove. This cannot be effected by passing water through the same channel that introduced the magma for filtration, but the wash water must be made to take quite another course. For simple washing, the efflux cocks with the long plugs are shut at the end of the filtration, those with the short plugs remaining open. The wash water is then let in through the water valve placed on the head piece, and eventually finds its way out through the cocks with the short plugs.

The foregoing method, however, is not quite satisfactory; if extraction of the soluble matters is worth doing at all it is worth doing well, and presses made for "absolute abstraction" should be employed. In order that this operation may be understood, we must refer to the following illustration

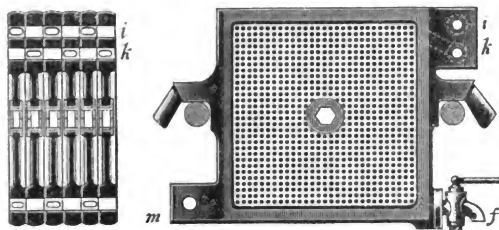


FIG. 79.—FILTER-PRESS PLATES.
Showing arrangements for washing, with absolute extraction.

(Fig. 79) which shows an elevation and section of a press chamber for absolute abstraction.

When the press has been filled to its full capacity, all the efflux cocks are shut and water admitted to the channel *m* shown in the illustration. This wash water rises through the cakes and leaves by the channel *k*, and this is continued until all the soluble matter has been carried away in the stream of water. The wash water leaving the channel *k* flows into the funnel pipe, shown at the head of the press, from whence it reaches the collecting trough. Care must be taken to open the air cock on channel *i* when the wash water is turned into channel *m*, or the water will not rise properly through the cakes.

Filter presses are generally made of cast-iron, but this is not always admissible, as iron might colour the product, or the liquid may corrode the press plate surfaces, and so render the press leaky under the usual pressures. Where iron is not admissible the press frames are made of wood, or aluminium, or the iron is galvanised, as is the case when employed for

glycerine. The plates can also be coated with lead, ebonite, or tin, whenever requirements render this necessary. In the installation of a filter press some previous experience in the pressing of various substances is absolutely necessary, and the author would recommend anyone desirous of making such an addition to his plant to avail himself of the stock of information possessed by the celebrated makers of these presses, who are always ready to place their knowledge at the disposal of intending customers. A little knowledge in the right direction and at the right time will often save the purchase of an unsuitable press.

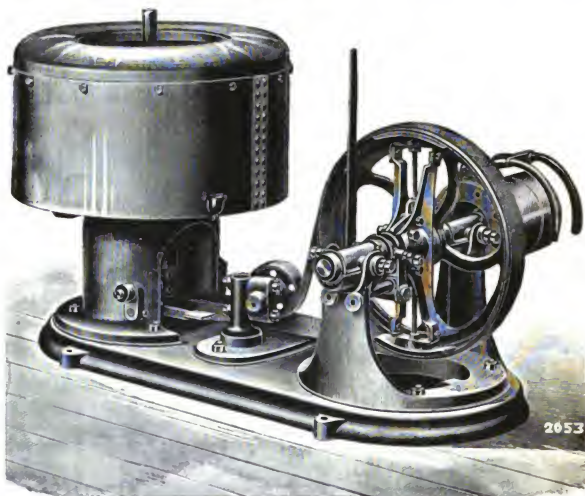


FIG. 80.—UNDER-DRIVEN HYDRO-EXTRACTOR.
(Watson, Laidlaw and Co.)

Hydro-Extractors — A method of separating liquids from crystalline or fibrous solids, and one that is much used, is that in which the centrifugal machine or hydro-extractor is employed. There are many different types of machine, but the principle upon which they all work is the same, viz., the rapid rotation of a perforated cage in which the material is placed, and which allows the solid material to stay in the cage, or basket as it is often called, whilst the liquid is pressed through into the casing. For fibrous material such as cotton waste, or the spent dyewood from an extractor, the centrifugal has no equal, and the same may be said of it for nearly all granular or crystalline substances, such as sugar and sulphate

of ammonia ; but it is not applicable to finely divided hydrated amorphous precipitates, or such crystals as break down under the centrifugal pressure. The following illustration will give a good general idea of the methods of fitting up ordinary hydro-extractors. Fig. 80 is the under-driven type made by Messrs. Watson, Laidlaw and Company, of Glasgow, which requires one and a quarter horse-power to drive the size having a basket two feet in diameter ; four horse-power for a three feet basket, and six horse-power for one of four feet. These powers are not required for the full period of the run of each charge, but ample power must be provided in order to get

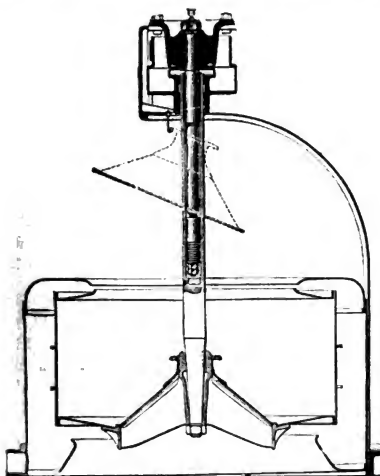


FIG. 81.—OVER-DRIVEN "SUSPENDED" HYDRO-EXTRACTOR.
(Watson, Laidlaw and Co.)

up the full speed of the machine without loss of time, and it is well to remember in this connection that the smaller machines are safer and materials are generally dried more thoroughly in them than in large machines.

The illustration above (Fig. 81) is an outline, partly in section to show Messrs. Watson, Laidlaw and Company's method of suspending their over-driven type of machine.

This hydro-extractor is constructed upon the principle of allowing the revolving basket to oscillate within certain limits so that it may be free to assume as a centre of gyration the centre of gravity of the basket and its load. When the load is evenly balanced (which is a great point in working all centrifugal machines) the basket will swing a little on starting

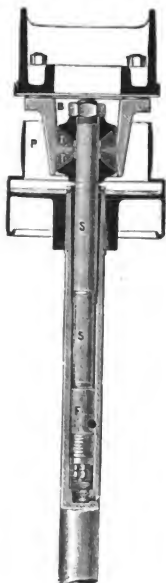


FIG. 82.—

and then spin perfectly true. When there is much inequality in the load, the basket will swing through a longer arc as it begins to revolve, but the oscillations will grow smaller and smaller as the speed gets up. The next illustration (Fig. 82) will show how this oscillation is counter-balanced and corrected.

A strong bracket B is bolted into the top beam, the latter being carried by the columns. An elastic buffer rests upon the bracket B, and it is this elastic buffer which permits and at the same time controls the oscillations of the basket or cage, thus preventing vibration in the framing of the machine. A steel spindle S is suspended from the buffer. This spindle is stationary, but is fitted with a special form of revolving Footstep F. The outer spindle is attached to the revolving footstep, and to it is fixed the pulley P by which the spindle and basket (which is attached to its lower end) are driven. The hollow part of the outer spindle thus constitutes an oil chamber, and so long as this chamber has a sufficient supply of oil, the footstep will be thoroughly lubricated.

The hydro-extractors made by Messrs. Broadbent and Sons, of Huddersfield, are constructed on quite a different principle. In this type, the machine itself is suspended on three pivots, and the spindle is directly driven by a small steam engine attached to the outer casing of the machine.

The illustration (Fig. 83) shows one of these hydro-extractors fixed ready for use, and the advantages of compactness, freedom from belts and counter gearing must be appreciated in many situations, as it is not dependent upon the services of any large engine, which may not be running when the

FIG. 83.—BROADBENT'S
DIRECT-DRIVEN HYDRO-EXTRACTOR.

hydro-extractor is required. Moreover, it is well known that a machine driven directly from a prime mover is subject to less loss of power than when belts or other transformers intervene. The remarks upon this subject in dealing with mechanical draught on page 36 may with advantage be read again, as they bear upon the driving of all appliances.

With hydro-extractors, as with many other machines, however, the saving of a small percentage of the power is often of less importance than the attainment of other conditions, and these must always be taken into account. Still, it is a distinct advantage to be able to operate each hydro separately, and there are several methods now by which this may be accomplished without the intervention of counter-shafting and fast and loose pulleys. The method of water driving, as adopted by Messrs. Watson,

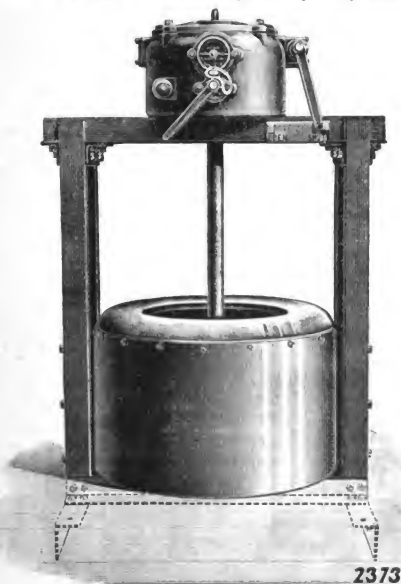


FIG. 84.—WATER-DRIVEN HYDRO-EXTRACTOR.
(Watson, Laidlaw and Co.)

Laidlaw and Company, is shown in Fig. 84. The prime mover is, of course, the steam engine, and the motor is a Pelton wheel on the centrifugal spindle which is shown in the illustration upon the overhead bracket. Each machine has its Pelton wheel, and the starting, running and stopping periods have no effect or influence upon any others in the battery. Moreover, the water drive is economical, as the running expenses are less than where belts intervene, or where small steam engines are running at high speeds. The water is used at a pressure of 150 lbs. per square inch, a steam

pump keeping up the pressure in the supply main, in a somewhat similar manner to the mains feeding a battery of hydraulic presses, or as employed in the United States for operating copper converters.

A very interesting set of trials has been made by Professor Watkinson, of the Glasgow Technical College, upon a battery of centrifugal machines constructed by Messrs. Watson, Laidlaw and Company, and driven by their patent water system. The report, given in full below, shows the high efficiency of this method of driving, which has much to recommend it :—

The battery tested consisted of three water-driven "Weston" centrifugals having baskets 30 in. diameter by 18 in. deep. The water for driving the centrifugals was supplied by a Duplex steam pump, having steam cylinders 16 in. diameter and pumps 8 in. diameter with a stroke of 10 in. The pump was connected to the battery by a pipe 3 in. bore by 17 ft. long, having two bends. This is exclusive of the main pipe on the battery with the small distributing pipes to each centrifugal.

Indicator diagrams were taken from each end of both steam cylinders simultaneously, and the water discharged was weighed. The cycle of operations was taken at six minutes, that is :—

Two minutes for acceleration to full speed.

" " " maintaining at full speed.

" " " stopping and emptying.

Each machine was fitted with two water valves having nozzles respectively 0·375 in. bore and 0·203 in. bore. The basket contained a load of 295 lbs. consisting of wooden boxes filled with iron borings. With a water pressure of 150 lbs. per square inch, the centrifugal was accelerated, in two minutes, to a speed of 1,247 revolutions per minute, the consumption of water being 550 lbs. per minute. With a water pressure of 150 lbs. per square inch, the centrifugal was maintained for two minutes at a speed of 1,247 revolutions per minute, the consumption of water being 127 lbs. per minute. With a water pressure of 150 lbs. per square inch, one centrifugal accelerating and one maintaining full speed at the same time, the consumption of water was 674 lbs. per minute. From the data obtained the following calculations were made :—

Indicated horse-power during acceleration	6·69
" " " maintaining	1·76
" " " full stop	0·118
	<hr/>
	3) 8·568

Average indicated horse-power for the cycle 2·856

Water horse-power during acceleration	5·78
" " " maintaining	1·34
" " " full stop	0·00
	<hr/>
	3) 7·12

Average water horse-power for the cycle 2·37

When one centrifugal was being accelerated and one was being maintained at full speed :—

The indicated horse-power was 8.19

The water horse-power was 7.10

From the above we see that the total loss of efficiency caused by leakage, internal friction in the pumps and steam cylinders, the loss in the valves, pipes, etc., was as follows :—

When accelerating one centrifugal
and maintaining one centrifugal
at full speed, loss of efficiency $\left(1 - \frac{7.1}{8.19}\right) \times 100 = 13.3\%$

When accelerating one centrifugal
only $\left(1 - \frac{5.78}{6.69}\right) \times 100 = 13.6\%$

When maintaining one centrifugal
only $\left(1 - \frac{1.34}{1.76}\right) \times 100 = 23.8\%$

The small loss of efficiency with this system under average conditions is due mainly to the fact that the speed of the engine and pump automatically varies in accordance with the demand for power by the centrifugals. With all other systems the steam engine and dynamos, or belt gearing, etc., run at a constant speed whether the demand for power by the centrifugals be great or small, and, in consequence, the frictional and other losses with these is much greater throughout the cycle than with the hydraulic system of driving.

Electrically driven hydro-extractors are now coming into use, and they have much to recommend them, though they cannot be so economical in motive power as either the belt-drive or the water-drive, for very obvious reasons; still, the motor is well out of the way, the workman can get completely round the machine, and one centrifugal is quite independent of any other, exactly as in the case of the water drive. The next illustration shows an electrically driven centrifugal machine as made by Messrs. Potts, Cassell and Williamson, of Motherwell.

Another form of hydro-extractor driven by an electro-motor is shown by Fig. 86, which is a machine made by Messrs. Summerscales and Sons, Ltd., the well-known laundry engineers, of Keighley. A 26 inch extractor takes a current of 17 ampères at 200 volts during the acceleration period, but runs under a full load with 6.5 amps.

The machine shown in the illustration is 30 inches in diameter, and with a similar current density to the foregoing requires 17 ampères at starting, but runs under a full load during the full speed period with 7 ampères, from which figures the student will be able to calculate the cost of running. In working centrifugals of medium size, it is usual to calculate upon a maximum of six journeys per hour, but this will depend greatly upon the ease with which the contents can be extracted from the cage at the end of the operation. The acceleration period generally lasts from two to three minutes, the machine is on full speed another two minutes,

while the stopping, emptying and recharging occupies the remainder of the time.

Hydro-extractors may be obtained to discharge their contents from the bottom of the cage or basket into a chute placed below the machine instead of having to lift out the dried charge from the top, and this is specially useful in many instances. The lifting out of crystals, etc., from the top of the machine is a slow, and often a dirty process, and this form of construction should be carefully studied by any intending purchaser.

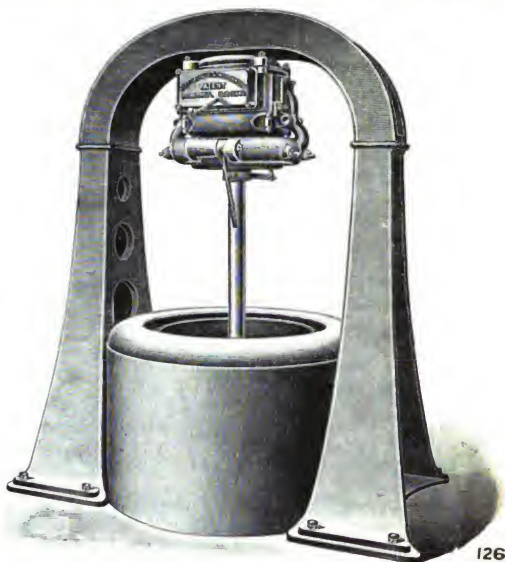


FIG. 85.—ELECTRICALLY DRIVEN HYDRO-EXTRACTOR.

The illustration (Fig. 87) shows a continental form of hydro-extractor with bottom discharge, and is much employed for dealing with commercial crystals, such as Glauber salts, soda crystals, muriate of ammonia, etc. The crystals, either before or after washing, according to the requirements of the case, are passed through this machine, and when discharged, are delivered into bags, so that no capacious drying room is needed as in many old-fashioned crystallising establishments.

Thus, in the manufacture of soda crystals, the large blocks are passed through a breaker, such as is shown by Fig. 234, Vol. I., from which they

fall in a broken condition into the hydro-extractor. Here the mother-liquor is extracted, and the crystals are ready for the market at once. Also in the sulphate of ammonia trade, the crystals are lifted directly into a centrifugal from the saturator, and are often bagged and sent out for shipment the same day.

We have seen that liquids may be separated from solids by means of the vacuum pump. A gauge will show us the vacuum that has been obtained, but the corresponding pressure upon the surface of the solid can never exceed that of one atmosphere. In practice it is seldom that

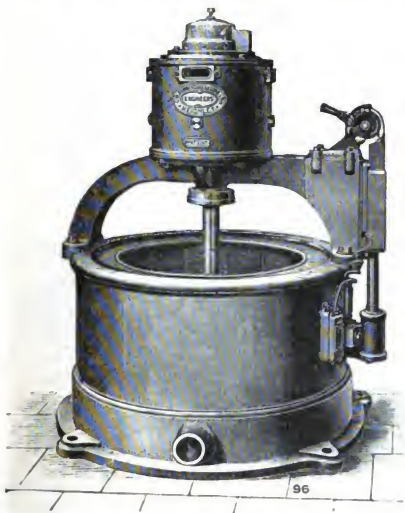


FIG. 86.—ELECTRICALLY DRIVEN HYDRO-EXTRACTOR.

25 inches of mercury is exceeded. We have also seen that the pressure may be increased by closing the filter and creating a pressure above the solid. In the filter press it is usual to pump the press until a certain pressure has been registered upon the gauge placed upon the inlet chamber. A very usual pressure runs from 40 lbs. to 60 lbs. per square inch; above these pressures filter cloths do not last very long, as the higher the pressure, the tighter the press has to be closed, and this is apt to cut the cloths round their edges. It is true that inlaid filter cloths can be used against perforated plates, but these are points that require careful consideration and discussion with the makers of the machines.

With hydro-extractors we have no ready means of showing the pressure exerted upon the material undergoing extraction, but, fortunately, this pressure may be readily calculated, and as the subject is intimately connected with the safety of such machines, it is well to point out how this may be done. The revolving basket of a centrifugal machine may be considered in the same light as the fly-wheel of a steam engine. Unfortunately, during the present year (1903), the newspapers have recorded the bursting of two fly-wheels in the cotton districts of Lancashire, resulting in loss of life,

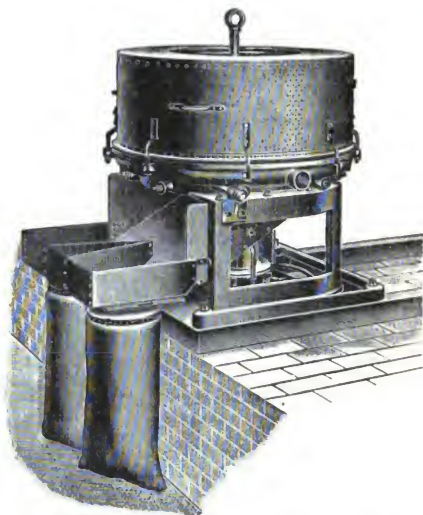


FIG. 87.—CENTRIFUGAL WITH BOTTOM DISCHARGE.
(Showing bagging arrangements.)

and the author has heard of several instances in which the cages or baskets of hydro-extractors have burst, with lamentable results. The shell of a steam boiler will only withstand a certain well defined pressure, and though the pressure is obtained by reason of the steam stored up within it, the problem is the same as in the hydro-extractor, where the pressure upon the shell or basket is the result of centrifugal force. This force is similar to that in a fly-wheel moving in a horizontal direction.

The centrifugal force C of a body in gyration is readily ascertained from the following formula :—

$$C = \frac{W v^2}{g r}$$

where W is the weight in pounds; v , the velocity; g , the force of gravity, 32; and r , the radius of the centre of gravity of the gyratory body. If we wish to express the result in pounds per square inch upon the cage of an ordinary hydro-extractor we must divide by a , which represents the extent in square inches of the revolving basket. If we represent the pressure in pounds per square inch by P .

$$P = \frac{C}{a} = \frac{W v^2}{g r a}$$

For many reasons, the baskets of centrifugal machines must be made light, so they are generally constructed for a maximum peripheral velocity of 200 feet per second. A general rule for safe speed in fly-wheel practice is 100 feet per second, though this is often exceeded nowadays. The old Yorkshire rule was a mile per minute, which works out to 88 feet per second.

Let us now apply the foregoing rule to a hydro-extractor having a three feet cage, running at a velocity of 150 feet per second in the plane of its centre of gravity, and loaded with a layer of six inches of chemical crystals, weighing 70 lbs. per cubic foot. The weight of the cage will be about 170 lbs., and its load of material 350 lbs., or 520 lbs. in all, so that $W = 520$; $v = 150$; $g = 32$; $a = 1,695$ square inches; while r may be assumed as 1.25 feet without being far from the truth. The calculation will, therefore, give us the pressure in lbs. per square inch:—

$$P = \frac{W v^2}{g r a} = \frac{520 \times (150)^2}{32 \times 1.25 \times 1,695} = 172 \text{ lbs.}$$

Let us now see what would be the effect of doubling the velocity so as to make $v = 300$ feet per second. Here the pressure per square inch would be:—

$$P = \frac{W v^2}{g r a} = \frac{520 \times (300)^2}{32 \times 1.25 \times 1,695} = 690 \text{ lbs.}$$

These calculations lead us naturally to the desirability of establishing a minimum effective velocity for the revolving cage, and to show the effect of reducing the velocity unduly we may go to the other extreme and imagine a speed of but 50 feet per second. Here

$$P = \frac{W v^2}{g r a} = \frac{520 \times (50)^2}{32 \times 1.25 \times 1,695} = 19 \text{ lbs.}$$

so it is easy to see why a quick speed should be kept up. A peripheral velocity of 200 feet per second is equivalent to 1,800 revolutions per minute on a basket two feet in diameter, or about 636 revolutions of a basket six feet in diameter.

Hydraulic Presses. — We must now pass to a class of operations where the pressure to be applied to the material is measured in tons per square inch instead of pounds with which we have previously been engaged. Oil extraction apparatus, in which suitable solvents are employed, has been already mentioned on page 160, but the oil pressing industry is a large

one both in this country and abroad, and several firms of engineers have devised plant of the highest efficiency for this purpose. Moreover, hydraulic presses are employed in many purely chemical establishments for the pressing of anthracene, naphthalin, stearine, paraffin, and other substances, that is to say, for the removal of the liquid matters accompanying them. In the manufacturing districts of Lancashire hydraulic presses are employed for baling cotton goods for export, and as improvements have been effected in packing-presses, the older ones have been replaced by those of newer type, the former adorning the second-hand machinery stores for a time until they are picked up by the economising manufacturer, who, when he desires to possess a hydraulic press cares but little about its construction or its suitability for his work so long as it is an hydraulic press. So it comes about that many of the presses in use are not models of high development; but this is not the case in the oil pressing industry proper, and therefore the presses and methods employed to illustrate this subject have been selected from the workshops of Messrs. Greenwood and Batley, Limited, of Leeds.

On account of the high percentage of oil contained in such substances as castor seed, coprah, sesame, and poppy seeds, palm kernels, and the like, it is only possible to extract the oil when the meal is confined in a cage pressing box, owing to the impossibility of keeping the meal from spreading and escaping from the presses when submitted to heavy pressure. In Messrs. Greenwood and Batley's method of treating these materials there is a battery of four presses as shown in the illustration (Fig. 88), all of which are fitted with pressing cages, and four are at all times under pressure. A fifth cage is shown near the heating kettle in the illustration, in what is called the compressor or extractor, and while four cages are in their several presses under pressure, this fifth cage is filled with meal to which a preliminary pressure is being given so that the cages may be filled to their maximum capacity, and be ready to replace a press cage as soon as it leaves one of the oil presses proper. This renders the pressing practically continuous, with the exception of the time consumed in withdrawing and replacing the pressure cages from the finishing presses. The pressing cages used in this system are so constructed that the meal when under pressure is retained in the cage during the time that the oil is being extracted, while the oil escapes freely into the oil receiving tank, which is fitted with several settling divisions. The pressure employed is a maximum of three tons per square inch at the ram of the press, and the capacity is about 15 cwts. per hour, according to the description of the meal and the time it is under pressure. It is not often that the whole of the oil can be expressed from a highly oleaginous material by one single pressing, and, therefore, a final pressing is usually adopted for such material. For this purpose, as well as for the extraction of oils from cotton-seed, rape, linseed, etc., the following description of press (Fig. 89) is most suitable. This form is made in three sizes, with rams 12 inches, 16 inches, and 18½ inches in diameter respectively, the size of the finished cakes being in each case the same—viz., 12 inches to 14 inches wide by 30 inches long, and the

capacity when working linseed runs from 42 cwts. to 45 cwts. per day of 11 hours.

In this press the oil flows into a large receptacle in the press bottom,

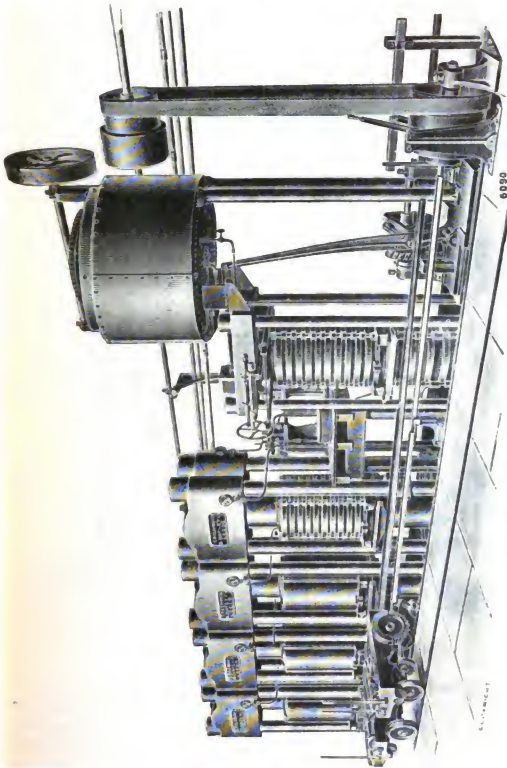


FIG. 88.—GREENWOOD AND BATLEY'S OIL PRESS.
(Combined "Leeds" and "Albion" System.)

so that there is no need for under-ground tanks and their objectionable surroundings. The press plates, made of forged and rolled steel, are suspended from the press head by means of wrought-iron links, an arrangement being fitted to the plates to prevent any undue longitudinal or trans-

verse movement. The press with 16 inch ram is the one most generally employed.

In the press just described, and also in the improvised press one so often sees in chemical establishments, the substance is folded up in cloths or bags of various material, in which it remains during pressure. These filled bags are placed between the plates of the press, which is then "pumped up." After some time it is again pumped if the gauge happens to show any loss, but of course the best principle is to ensure that the full pressure

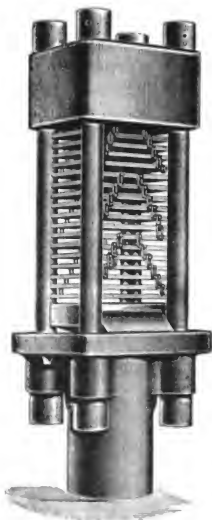


FIG. 89.—"ANGLO-AMERICAN"
OIL PRESS.



FIG. 90.—ALBION OIL PRESS.

be constantly maintained, especially in such cases as when steaming reduces the bulk of the material. This heating of the cakes during pressure is an absolute necessity in dealing with certain materials such as anthracene, and is usually effected by enclosing the whole press in a waterproof covering or in a wooden chamber that can be tightly closed, and turning in open steam. This is a messy process at the best, but it is improved by the use of heating plates, in the interior of which steam is made to circulate.

Hydraulic presses for naphthalin, which work without packing, are made at Koeber's Ironworks at Harburg, near Hamburg. As this is an

important development, an illustration of one of these large presses may be found in Fig. 91.

The plant consists of the main press fitted with a revolving apparatus for changing the strainers from one ram to the other, as shown in the illustration. Two press strainers may be turned round one of the press columns in such a manner that whilst one of them is under pressure in the main press, the cakes are removed from the second by means of a special throw-out apparatus. When all the cakes have been pressed out of the strainer, the plunger is reversed, and the strainer again becomes filled with raw naphthalin whilst running down. The raw salts are supplied from an overhead mixing vat, which serves at the same time for warming the material when necessary. The cakes are separated by iron plates, and when the plunger is at its lowest point the empty strainer is just filled with the raw material. By means of the wheel shown in the illustration, the turning of the strainer is effected by one man quite easily, and the newly filled strainer is similarly conveyed into the main press, while the fully pressed material is turned into the throwing out apparatus. The strainers are 41 inches in height, with an inside diameter of 19 inches, and they each hold about 4 cwt. of naphthalin, the daily capacity averaging from 7 to 9 tons, for which quantity two men are sufficient. The strainers are free to move in a vertical plane between cast-iron guides. They are furnished with two casings, the inner casing performing the operation of straining. The cakes are submitted to a pressure of 350 atmospheres (about $2\frac{1}{2}$ tons to the square inch) by means of a ram having a diameter of 18 inches.

According to the size of the plant, the pump has two, three, or four direct-acting plungers, or the press can be worked from an accumulator. The plungers are worked from a common shaft, and the cranks are set at an angle of 90° to give an even strain on the belting. A set of these pumps is shown in Fig. 91*.

Smaller installations than those shown by Fig. 91 are also made. In these the strainer is 32 inches high by about 16 inches diameter, holding about $3\frac{1}{2}$ cwt. of naphthalin, and the press can be filled and emptied in about an hour. There are no press cloths employed with these presses, and from a sample of pressed naphthalin examined by the author, the cold pressed cake possesses a melting point of 77° C.

The application of pressure to hydraulic presses is a subject that should be mentioned here, as the need of good installations for various purposes in the chemical trade appears to be growing. A factory running several presses and requiring steady work will need an accumulator, against which the pressure pump delivers its water. The pump, of course, must be of special pattern, strongly built to withstand the great pressures it will have to bear. There is no need to describe or illustrate the old fashioned pair of hand pumps one so often sees in chemical establishments, with its 2-inch and half-inch rams standing upon the water cistern, but it may be as well to both illustrate and describe the Worthington hydraulic pressure pump, which is one of the best for this kind of work, and is shown in Fig. 92, which represents a pump having 10 inch steam cylinders, $2\frac{1}{2}$

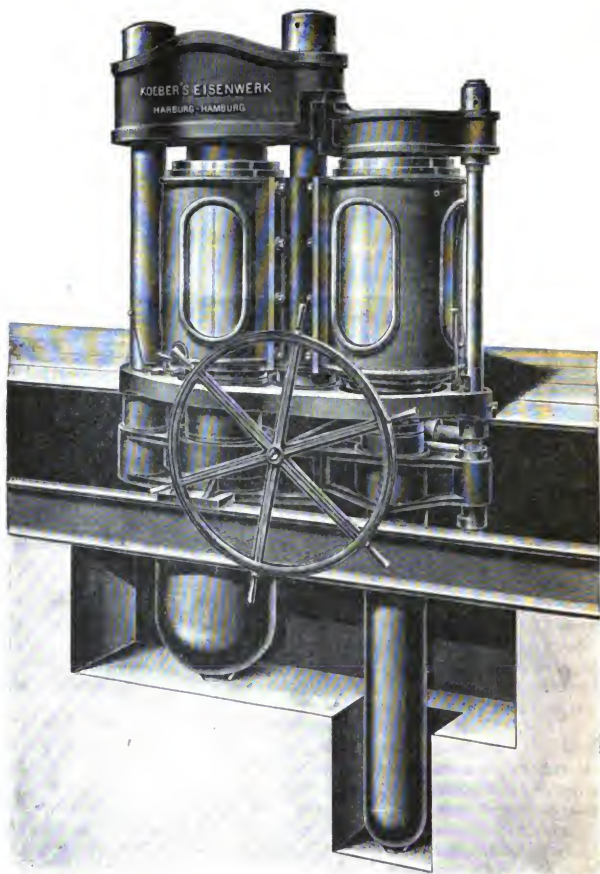


FIG. 91.—KOEBER'S HYDRAULIC PRESS FOR NAPHTHALIN.

inch water cylinders, with a 10 inch length of stroke. This pattern of pump has been especially designed for working hydraulic lifts and cranes, for cotton packing and hydraulic presses generally, and they are also used for oil pipe lines and such other services as may require the delivery of liquids against heavy pressures. In this pump the ordinary interior double-acting plunger is replaced by two plungers or rams, having external adjustable packings, which are readily renewed, and which work into each

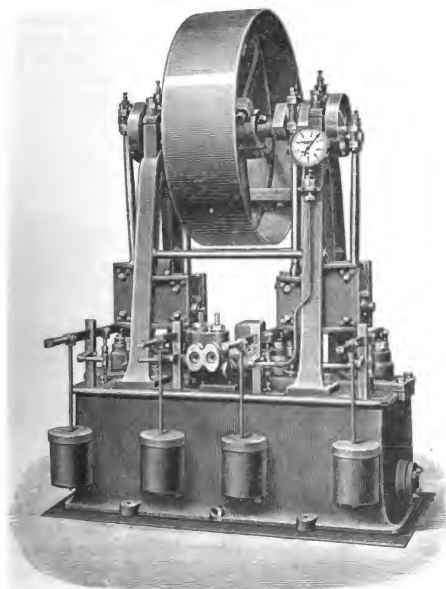


FIG. 91*.—KOEBER'S HYDRAULIC PUMPS.

end of a cylinder having a central partition. The plungers are connected together by yokes and exterior rods in such a manner as to cause them to work together as one plunger, so that while one is drawing the other is forcing the fluid, thus making the pump double-acting. The valve boxes are designed as small separate chambers easily accessible and capable of resisting very heavy pressures. The arrangement shown in the illustration is one only of many forms of this type of pump, but the general characteristic of independent plungers with exterior packing refers to them all.

The readiness with which the valves may be examined is also a feature of this pump.

In any well arranged hydraulic installation an accumulator will be found as one of the fixtures, and to it will be coupled an arrangement for stopping and starting the pressure pump when the ram of the accumulator passes certain maximum and minimum positions. The ordinary accumulator consists of a weighted vertical ram working in a strong cylinder of water, of small diameter, the weight being proportioned to the pressure required and the diameter of the ram. The high pressure main is connected with the base of the ram cylinder and the pressure exerted by the weighted ram is transmitted to the whole series of machines worked from the main. When the high pressure water escapes from the presses or lifts, or cranes, or whatever appliance it is used for, it runs into a well or cistern and is drawn again through the pump.

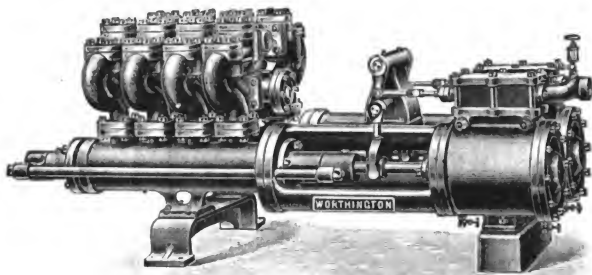


FIG. 92.—THE WORTHINGTON HYDRAULIC PRESSURE PUMP.

The water accumulator is not the only form of appliance for storing hydraulic power, as steam accumulators have been known for many years, though it is only within a very short period that they have been made trustworthy. Fig. 93 shows a steam accumulator made by the Worthington Pumping Engine Company, to which we must give a little attention. It consists of an ordinary steam cylinder, such as would be used in a steam engine (except that it has no ports or valves) combined with a ram cylinder similar to that of a weighted accumulator. Instead of heavy weights, a steam piston, acted upon by a fixed steam pressure, exerts the necessary force on the ram. The ram is securely bolted to the piston and passes through two stuffing boxes, one in the steam cylinder head and the other in the ram cylinder. The stuffing box in the steam cylinder is lightly packed, as its only office is to prevent the leakage of the exhaust steam, which is let into the back end of the steam cylinder to keep the walls of the cylinder and the piston hot. The supply of steam to the pump is

regulated to meet variations in the consumption of water in the following manner :

The regulating pipe consists of a polished perforated tube of suitable diameter, which is connected at one end to an opening through the centre of the accumulator steam-cylinder head, and passes longitudinally through

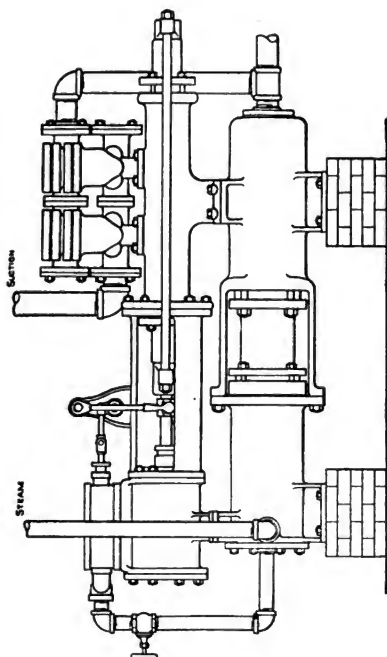


FIG. 93.—THE WORTHINGTON STEAM ACCUMULATOR.

the centre of the accumulator steam piston into the interior of the ram casting, the joint between this pipe and the steam piston being made by a long self-adjusting sleeve. The steam supply to the pressure pump is taken from the interior of the accumulator steam cylinder, through the perforations of the regulating pipe, thence through the steam cylinder head to the pump, the holes in the regulating pipe being distributed spirally throughout its length.

The position of the accumulator steam piston, which depends on the amount of water in the ram cylinder, governs the number of holes in the regulating pipe which open into the steam cylinder, and so controls the amount of steam supplied, and hence, the speed of the pump. When in use, as the ram cylinder fills, the speed of the pump decreases, until, just before the steam piston reaches the head of the accumulator cylinder, all the holes in the regulating pipe are shut off by the sleeve in the steam piston, thus stopping the pump. As the water is drawn off from the ram cylinder, the number of holes uncovered in the regulating pipe gradually increases until enough are open to drive the pump at its full speed. By this arrangement variations in the speed of the pump are gradual, which is essential to the quiet operation of a heavy-pressure pump on a variable consumption of water. It will be seen that the line drawing (Fig. 93) shows a steam accumulator and pressure pump combined.

It may be of interest to give here a rule for finding the thickness of metal for the cylinders of hydraulic presses and for other hydraulic work. This information may be obtained from Barlow's formula, already given on page 168, Vol. I., which is:—

$$T = \frac{P R}{S - P} = \text{thickness in inches.}$$

Where P = the pressure exerted in pounds per square inch,

R = the radius of the cylinder,

S = a coefficient for the strength of the metal, 16,000 for cast-iron, and 40,000 for steel, and

T = the required thickness in inches,

so that the thickness of a steel cylinder 12 inches in diameter, to withstand a pressure of 4 tons per square inch, should be:—

$$T = \frac{P R}{S - P} = \frac{8,960 \times 6}{40,000 - 8,960} = 1.7 \text{ inches}$$

If cast-iron had been employed in the construction of the cylinder, the formula would show:—

$$T = \frac{P R}{S - P} = \frac{8,960 \times 6}{16,000 - 8,960} = 7.6 \text{ inches.}$$

In the "American Machinist" of New York for April 11th, 1903, F. B. Kleinhaus discusses the proportions of the cylinders of hydraulic presses, and seems to have noticed that they generally rupture at a point near the junction of the side walls with the bottom, that is when they rupture at all. He therefore advises the lower portions to be made of extra thickness according to the following formulæ:—

$$T_2 = R \sqrt{\frac{2P}{3S}}; \quad T_3 = R \sqrt{\frac{P}{S}}.$$

T_2 being the thickness of the walls in the lower third, while T_3 represents the thickness of the bottom itself. If we assign the foregoing values for steel to these equations, we shall find that the lower portions of the walls of the cylinder should be thickened to 2.4 inches, and the bottom of the cylinder to 2.7 inches in the foregoing illustration.

CHAPTER III.

ABSORBING AND COMPRESSING GASES.

An operation of the greatest importance in all chemical manufacturing operations is that of the absorption, or, as it is sometimes called, the condensation of gases. The tower apparatus in which hydrochloric acid gas is absorbed on the large scale is not infrequently styled a condenser, but in this chapter at least it is desirable that a distinction should be drawn between these terms. Absorption may be described as the solution of a gas or vapour in some liquid menstruum, or in some specially prepared solid ; while the term condensation is better applied to operations in which distillation plays a part, and where the recovery of the volatilised liquid forms a necessary part of the process.

It is true there are many processes that at first sight do not appear to be so well defined as to enable them to be placed on either side of this dividing line, but a little consideration will enable anyone to overcome this difficulty. An instance of this occurs in the sulphuric acid manufacture, where the various gases entering into the reaction are dealt with in leaden chambers. The operation is generally spoken of as one of condensation, but it is extremely doubtful whether this is a correct description of the chemical and physical reactions that occur as interpreted by the distinctions already proposed. Anyhow, the place to be occupied in any description of such a process, whether correctly localised or not, does not in any way interfere with the classification proposed, and, later on, this manufacture will be considered as an absorption process taking place in an apparatus suited to the circumstances of the case. A part of the sulphuric acid manufacture, however, taking place outside of the leaden chambers is undoubtedly an absorption process, and this has been recognised by the fact that by common consent the apparatus in which the operation takes place has been called the "absorbing tower," that is to say, the tower in which the nitrous compounds are absorbed in strong sulphuric acid, and this is the counterpart of the "condenser" of the hydrochloric acid maker, in which the hydrochloric acid gas is absorbed in water.

Having specified these distinctions, it may be as well to consider the several problems under the heads of (a) absorbing pure gases in liquids ; (b) absorbing pure gases by solids ; (c) absorbing mixed gases by solids ; and (d) absorbing mixed gases by liquids.

Absorbing Pure Gases by Liquids — The absorption of a simple gas, unmixed with other gases, by water or other desired liquid, may be readily illustrated by two processes with which the maker of heavy chemicals will be familiar. These two processes are: First, the manufacture of "cylinder" muriatic acid (HCl in water; 42°Tw.); and second, the production of liquor ammonia of 0.884 sp. gr. In the first of these processes, common salt is acted upon by sulphuric acid of about 150°Tw. in proportions to form sodium bisulphate, and thus liberates the whole of the chlorine as hydrochloric acid gas. This gaseous product is in most works in this country passed through a series of "Wolff bottles," or as they are technically termed, "jars," or "receivers," the Continental form of which is shown in Fig. 94. The English form is cylindrical and is preferred by many manufacturers, though, in the author's opinion, there is nothing to choose between them, the life of a receiver being chiefly dependent upon the carefulness with which it has been used. To turn hot gas into a jar of hot weak acid, as is



FIG. 94.—A PORTION OF A SET OF WOLFF BOTTLES.

done in some cases, is simply to court disaster and breakage. The HCl gas liberated from the "cylinder," or decomposing vessel, enters the first jar of the series which is connected to the second jar by a connector, and this to the third jar, and so on throughout the series until it comes to the last jar, one neck of which is generally open to the atmosphere. The number of jars employed in a series varies from 12 to 20 according to the work that is to be done in them.

We ought now to consider the changes that go on when the foregoing process is being worked, so that we may be able to design plant to give us the best results. In the first place, pure hydrochloric acid gas is required, and as free as possible from water vapour, as any steam that is formed will enter the first jar, and giving up its latent heat to the contents, impede the absorption. The jars being three-fourths filled with cold water speedily absorb the hydrochloric acid gas that is passed over its surface—the solution becomes heavier, and so tends to establish an efficient circulation, at the same time becoming stronger, until at the temperature of working it refuses to absorb any more of the gas. Another point of great importance must not be overlooked. The bulk of chemical substances give out heat on solution or

absorption by water (fully hydrated crystals being in most instances exceptions), and the heat of solution of all the more commonly occurring chemical substances has been carefully ascertained by several observers and recorded. Berthelot has described a research undertaken to ascertain the heat of solution of hydrochloric acid, and he found that when 36.5 grammes of this gas are absorbed by 200 molecules, or 3,600 grammes of water, no less than 17,430 centigrade-gramme units of heat are evolved, a quantity that would be sufficient to raise the temperature of the absorbing water to the boiling point when only half saturated with the gas. This heat is equal to 477 C.H. units per pound of hydrochloric acid. The heat evolved by the solution of this gas in water is not, however, a constant quantity, as it varies with the amount of water present. Thomsen has shown that in all probability there exists a monohydrate of hydrochloric acid ($\text{HCl.H}_2\text{O}$) in all solutions of this acid, and, further, that the heat evolved by the dilution of a strong acid with water may be expressed by the formula:—

$$\left(\frac{1}{n'} - \frac{1}{n' + m} \right) 11,980$$

where n' represents the number of molecules of water accompanying each molecule of HCl in the stronger acid, and m the number of molecules of dilution water. This formula will give 11,940 C.H. units as the heat of dilution of one molecule of gaseous HCl with 300 molecules of water, whereas Thomsen actually found 17,316 units, so that the difference, or 5,376 units, must represent the thermal value of the absorption of one molecule of gaseous hydrochloric acid in forming the liquid hydrate $\text{HCl.H}_2\text{O}$.

If we take 42° Tw. acid as being composed of 42 parts by weight of HCl and 58 parts of water, or 2.8 molecules of water to each molecule of HCl, we shall find that the calculation for determining the total amount of heat liberated during the formation of hydrochloric acid of 42° Tw. from 36.5 lbs. of HCl works out as follows:—

$$\left\{ \left(\frac{1}{1} - \frac{1}{1 + 1.8} \right) 11,980 \right\} + 5,376 = 13,078,$$

which is equal to 358 C.H. units per pound of HCl. All this heat will have to be dissipated before hydrochloric acid of 42° Tw. can be obtained.

Let us neglect the latent heat of the steam accompanying the hydrochloric acid gas from the decomposing cylinder, as by keeping the heat of the furnace well under control nearly all the water of the sulphuric acid introduced with the salt may be retained in the fused bisulphate of soda. In this case, the hydrochloric acid gas alone will pass forward into the receivers.

If a charge of 1,000 lbs. of 90 per cent. salt be decomposed, it will yield 560 lbs. of hydrochloric acid gas, which will require 770 lbs. (or 77 gallons) of water for its absorption—contained, say, in three of the usual jars or receivers attached to the cylinder. Let us presume that 12 receivers are the complement to this special cylinder, and that the operation of decomposing the salt, absorbing the gas, and cooling, will occupy a period of 24 hours. In this time there will be evolved—

$$560 \times 358 = 200,480 \text{ C.H. units.}$$

Now the surface exposed to the cooling influence of the atmosphere is approximately 12 square feet for each receiver, so that this battery of 12 will expose 144 square feet of cooling surface, and if this surface loses the foregoing number of heat units in 24 hours it will amount to—

$$\frac{200.480}{12 \times 12 \times 24} = 58 \text{ c.h. units per sq. ft. per hour.}$$

The hotter jars will lose more, and the cooler jars less than the foregoing average figure, but enough jars will have to be provided in the series to fully disseminate during the period of working the 200.480 heat units evolved by the absorption of the 560 lbs. of hydrochloric acid gas.

It will be seen that if the heat of formation and dilution could be regularly abstracted as fast as it is evolved there would be no need for more than three receivers, but under this system of absorption that is not an easy task; still, coolers formed of a hollow earthenware coil through which cold water flows, have been adopted in some works with success, but it is doubtful whether there is any advantage in their use over the plan of having a sufficient number of receivers to disseminate the heat.

A number of receivers over and above those necessary to hold the water required for one charge, converts the process to one of stage absorption, and if the water used for absorption is all made to pass through the last jars of the series, while the first jars are holding nearly finished acid, it will be readily seen that much less heat will be evolved in the finishing receivers than if water had been placed in them. In designing plant, then, for the absorption of gases by a liquid, in which heat is evolved, care should be taken to provide ample cooling surface, to ensure sufficient circulation in the contents of the absorbing apparatus, and to ensure that the strong gas comes into contact with the nearly saturated and cooled solution.

In the process just mentioned, the hydrochloric acid solution in water becomes heavier with the increment of hydrochloric acid gas, which causes a movement of the solution, as may be readily seen by performing the operation in a glass vessel. A heavy superstratum is formed which sinks in the lighter fluid below, until equilibrium is established, but in such cases as the absorption of ammonia gas, the solution being relatively lighter than water forms a layer on the surface of the absorbing fluid, and absorption practically stops. It is quite certain, then, that an apparatus designed for the absorption of hydrochloric acid gas would scarcely operate successfully if it was attempted to make a solution of ammonia in it.

Unlike hydrochloric acid, which is made to travel over the surface of the absorption liquid, ammonia gas must be made to bubble through it, and here our first difficulty comes in. If the absorption vessels are too large in comparison with the generator, or, in other words, if there be not a sufficient stream of gas passing, there is great danger of a vacuum being formed, which would suck back the whole of the absorbing liquid and its ammonia contents into the generating vessel, and the work would have to be commenced again. Simple valves will, of course, prevent these mishaps, if they are properly placed and looked after, but in the absence of such appliances many annoying accidents are likely to happen.

Ammonia gas, like hydrochloric acid gas, evolves heat on absorption by water, but it does not appear to form a hydrate as the latter does. The heat evolved by the absorption of one molecule in grammes of gaseous ammonia ($\text{NH}_3 = 17$) in water is 8,800 c.g. units, or 518 c.g. units per each one part by weight of ammonia. This is 518 C.H. units per pound, and, like the process just described, the whole of this heat must be carried away in order that strong liquor ammonia may be produced. Liquor ammonia of 0.884 sp. gr., containing 36 per cent. of ammonia, cannot be made except with cold water and very efficient cooling during the process of absorption. The coefficient of absorption of ammonia gas by water for various temperatures at the atmospheric pressure may be calculated from the formula given by Carius, which is:—

$$\beta = 1049.624 - 29.4963t + 0.6768t^2 - 0.00956t^3$$

which gives the following numbers, indicating the volumes of gas absorbed by one volume of water:—

0° C.	5°	10°	15°	20°	25°	30°	35°	40°
1050	970	810	728	652	585	515	450	382

On the large scale, the absorption of ammonia gas in water is generally carried on in lead lined vessels. The vessels themselves may be either of timber or iron, but timber is generally preferred. The ammonia gas is conducted to the bottom of the vessel containing the water, and a cooler, composed of a coil of leaden pipe through which cold water is made to flow, is placed in the vessel itself so as to be in immediate contact with the solution of ammonia. This coil should be of ample size, as a large heat difference between the cooling water and the contents of the absorber cannot be allowed. Here, the advantages of artificial refrigeration would be found useful, as many sources of water supply are too warm for this purpose in the summer.

Water at 15° C. will absorb 728 volumes of ammonia gas under the ordinary pressure of the atmosphere, which is approximately the point of saturation for 0.884 liquor ammonia, 100 parts by weight of which contain 36 parts of ammonia and 64 parts of water.

In a works of which the author had one time charge of the manufacturing processes, liquor ammonia was made from the washings of the spent oxide from gas works. These, at 10° Tw. (sp. gr. 1.05), were boiled with excess of milk of lime, yielding, at the first operation, a "crude" liquor of 0.950 sp. gr., containing 12.5 per cent. of ammonia and having a boiling point of 66° C. This "crude," as it was called, was then gradually heated in the finishing still with coil steam to 70° C., when 70 per cent. of ammonia came over as a dry gas, and after purification was passed direct into the absorbing vessels. The temperature of the contents of the finishing still was then raised to 100° C., and the distillation continued until the whole of the liquor produced during the second stage of the distillation marked 0.950, which was sent into the "crude" tank for re-heating. The contents of the still were then blown with open steam until all the ammonia was driven off, and this distillate was returned to the crude still.

The "absorbers" were each five feet long, three feet wide, and 18 inches deep, inside measurement, and were worked in a series of three, but as they could only be filled with 12 inches of water, on account of the expansion of the liquor during absorption, each vessel would only contain 15 cubic feet of water, or 937 lbs. These 937 lbs. of water would absorb 527 lbs. of ammonia to form 1,464 lbs., or 16 carboys, of liquor ammonia of 0.884 sp. gr.

Let us now see what heat is developed by the absorption. We have already seen that one pound of ammonia evolves 518 C.H. units on solution in water, so that 527 lbs. of ammonia will develop—

$$527 \times 518 = 272,986 \text{ C.H. units,}$$

and as the operation generally lasted 10 hours, this amounts to 27,298 C.H. units per hour. The cooling coil contained 30 square feet of cooling surface in each absorber, so that each square foot of cooling surface had to carry off 910 C.H. units of heat per hour. If the cooling water had only been heated 1° C. during its passage through the absorber, the volume consumed would have been 91 gallons per hour; but, as there was a series of three absorbers, the cooling water passing through each in turn, and the bulk of the work being done in the second vessel, where the gravity was 0.910 or 25 per cent. of ammonia, there was no need to use the water so extravagantly. As a matter of fact, the cooling water usually entered the coil of the first absorber at 10° C., and left the third vessel at 15° C., so that only 18 gallons of cooling water per hour would be required. If the heat were not extracted as evolved—in other words, if there had been no heat losses—it will be found that sufficient heat was evolved during the operation of each charge to have raised the temperature of the water in the three absorbers from 10° C. to above its boiling point, thus:—

$$10 + \frac{272,986}{937 \times 3} = 107^{\circ} \text{ C.}$$

It will be seen from the two foregoing examples that the absorption of pure gases by liquids is usually a comparatively easy problem, when all the details are taken into consideration, as the operation is generally not complicated with anything save the heat of absorption. There are many processes however where the heat of absorption is not so apparent as in the two instances just described, and where this heat is small it may usually be neglected, as the apparatus will allow of its dissipation without any special precautions being taken. The heat is there nevertheless. An instance in point is the precipitation of arsenic sulphide in the manufacture of de-arsenicated oil of vitriol and hydrochloric acid free from arsenic. In both of these cases sulphuretted hydrogen is employed to remove the arsenic, and the form of the apparatus in which the absorption takes place is no mean factor in establishing the success of the process. The arsenic exists in ordinary chamber acid, both as arsenious acid and as arsenic acid, while more often than not, the operation is complicated by the presence of nitrous compounds, which must be taken into account.

When we absorb hydrochloric acid gas in water or ammonia in water, we commence and end with a clear liquid substantially free from sediment,

but in de-arsenicating sulphuric acid or hydrochloric acid, the liquid quickly becomes a magma of acid with the precipitated sulphide, which destroys its mobility, and makes special apparatus necessary for the absorption. The amount of arsenic present in the acid naturally has a considerable influence upon the operations, but we are not concerned with anything more than the absorption here, though it may be necessary to state that when the maximum quantity of sulphuretted hydrogen has been absorbed, it results in a magma, which, on subsidence, yields very varying quantities of clear liquor and sediment. An ordinary chamber acid from Rio Tinto pyrites will yield about 66 per cent. by volume of clear de-arsenicated acid and 34 per cent. of arsenic mud, while acid highly charged with arsenic, such as that coming from the Glover tower, will often only yield 10 per cent. of clear acid and 90 per cent. of arsenic mud.

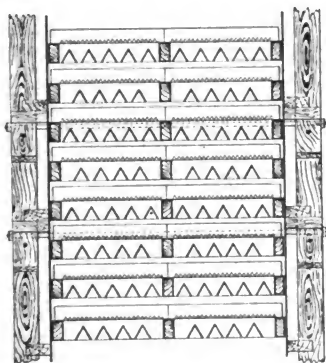


FIG. 95.—SECTION THROUGH DE-ARSENICATING TOWER.

The absorption of the sulphuretted hydrogen in the foregoing instances is usually effected in what is styled a "de-arsenicating tower." It is a leaden tower upon the style of a "Gay-Lussac" or absorbing tower, but instead of being filled with coke packing, as an absorbing tower usually is filled, it is provided with leaden triangular packing, as shown in the accompanying illustration. If the tower were packed with coke in the usual way, or even with tower rings or bricks, the interstices would become speedily choked with the arsenic sulphide mud, but, as the slope of the triangular packing is greater than the angle of repose for the mud, the bulk of it is carried down to the lower part of the tower and escapes with the stream of issuing acid. A tower of this form is worked practically closed. The top is certainly luted for the escape of any surplus gas that might require a vent, but as a rule there is but little escape, although the whole of the triangular bars are surrounded by the sulphuretted hydrogen atmosphere.

The nitrous gases, when present, destroy their equivalent of sulphuretted hydrogen, and, again, a more prolonged contact is necessary for the precipitation of the arsenic when it is present in the form of arsenic acid. The arsenic acid first requires reduction to the arsenious state, and is then quickly precipitated by sulphuretted hydrogen.

The heats of formation, absorption, and solution come into play here just as they do in the cases already described, but no inconveniences have been experienced, on account of the ready manner in which the construction and disposition of the apparatus lends itself to the dissipation of heat. A de-arsenicating tower presents a cooling surface of about 300 square feet, and will de-arsenicate not less than 1,000 lbs. of acid per hour containing 0.4 per cent. of arsenic, or 4 lbs. per hour. Now, if we reckon the thermal value of the equation :—



as being 1,000 C.H. units per pound of arsenic, we have the amount of heat as 4,000 C.H. units, which are sufficient to heat up the 1,000 lbs. of acid (sp. heat 0.5) by 8°C ., if no heat be lost by radiation from the tower itself. In all probability, however, the acid diluted for de-arsenication will be more than this number of degrees above the temperature of the air, and, heating the tower surfaces, will thus escape. It will be seen that there is ample provision for the escape of heat, as the 300 square feet of tower surface would only be called upon at the utmost to dissipate 14 C.H. units per square foot per hour.

The foregoing method of de-arsenication has many inconveniences. The small velocity of the flow of acid over the triangular leads results in the adherence of the sulphide of arsenic to them in gradually increasing quantity as time goes on, forming at last cauliflower-like masses, which entirely choke up the interstices. Then comes the period of cleansing, and a pleasant experience it is for all concerned in it. The tower has to be cut open and "the matter in the wrong place" displaced with the best means at the workmen's disposal, the process being by no means a fragrant one. In the author's apparatus, which was specially designed to overcome the foregoing troubles, the operation is performed in an apparatus somewhat after the pattern of Fig. 101, but modified to suit the circumstances. The sulphuretted hydrogen is blown by means of a fan into the lower chamber of the absorber, under a pressure of about 16 inches of water, and the excess of gas when it reaches the outlet of the vessel is passed round to the suction side of the fan. In this manner a very large volume of sulphuretted hydrogen is kept circulating, or, to be more accurate, a small volume is many times circulated, the loss by absorption being automatically supplied from the generator. The agitation produced by the rapid injection of the sulphuretted hydrogen is sufficient to keep the surfaces free from deposit, and the sulphide of arsenic is completely carried away in the current of de-arsenicated acid which runs in a continuous stream from the de-arsenicator. The efficiency of the apparatus is so great that 200 tons of chamber acid per week can be successfully treated in a de-arsenicator only three feet in diameter and eight feet high. The generator is constructed on the principle of the plumber's

hydrogen machine, illustrated on page 165, by Fig. 60. As the acid is de-arsenicated at 110° Tw., the vessel is constructed of cast-iron, upon which acid of that strength has little or no action. Indeed, at 100° Tw., the action is so slight as to be inappreciable, but there is no necessity to deal with acid of so low a gravity.

When the heat of reaction, or of absorption, does not display itself in a striking manner, there is often a tendency to neglect its presence and the influence it may exert upon large scale working. In small experiments, the apparatus usually dissipates the heat very quickly, and removes it from observation, but it has been there nevertheless. A good instance of this may be found in the absorption of chlorine by milk of lime in the manufacture of bleaching liquor. In the good old days of chemical manufacturing, bleaching liquor was made in large stone tanks, constructed of stones varying from ten inches to twelve inches in thickness; in fact, everything was done in those days to prevent the heat from escaping, and so it came to pass that when the temperature of the solution rose abnormally, those in charge of the operation would simply shut off the current of chlorine and sit down to watch the solution until it had cooled. It took a long time to adopt the comparatively thin cast-iron absorbing vessel, and still longer to introduce a water-cooling jacket. In fact, it was only recognised in a very hazy manner in those days that heat was a necessary concomitant of the reaction.

The Absorption of Pure Gases by Solids.—The manufacture of bleaching powder furnishes us with an instance where it is necessary to take away the heat of formation as rapidly as possible, and at the same time it affords an illustration of the absorption of gases by solids. In this manufacture, the slaked and sieved lime ($\text{CaO} \cdot \text{H}_2\text{O}$) is spread upon the floor of a chamber which is built of lead in much the same manner as a sulphuric acid chamber, and therein is exposed to the action of pure chlorine gas. These chambers are all built six feet in height, and it has come to be regarded as an axiom that 160 square feet of floor surface are needed for each ton of bleach made per week, so that a chamber 80 ft. by 20 ft. is called a ten-ton chamber. Now, as the floors of these chambers are generally made as impervious to the passage of heat as they well can be, consisting of thick floor boards covered with tiles or Yorkshire flags, the only ready means of heat escaping is by the sides and top. A chamber 40 feet square would therefore have less cooling surface than a chamber 80 ft. by 20 ft., in the proportion of 25 to 28, showing clearly that the floor area is not a satisfactory basis to reckon from, and where air-cooling only is resorted to, the cooling surface should not be less than 280 superficial feet per ton of bleaching powder made per week.

Neglect of provision for the escape of the heat resulting from the reaction of chlorine upon calcium hydrate has caused disappointment to several inventors. In one mechanical bleaching powder chamber, built to do ten tons per week, and from a purely mechanical point of view admirably designed, the heat was so intense after an hour's working that the hand could not be placed without discomfort upon the iron plates of which the chamber

was composed. Being called upon to give an opinion on this chamber, the author stated that its capacity was 25 cwts. per week instead of ten tons, and there is but little doubt that if the apparatus had been worked at the lower output it would have been successful. Hargreaves, in 1871, devised a cylindrical tower, after the style of the McDougall calciner (page 108) for the absorption of gases by solids, but so far as the author is aware no real attempt has ever been made to make such an apparatus successful for the absorption of pure chlorine gas by lime. One point in the behaviour of pure gases in apparatus, such as the ordinary bleaching powder chamber, must not be forgotten, as it has an important bearing on the construction of plant. Chlorine gas is heavier than air, and on its entering the chamber (at the top), it falls to the bottom and covers the bed of lime there, displacing the air which rises on the top of it almost as perfectly as if the chlorine were a liquid such as water. By this means the air is completely displaced from the chamber, and escapes by an air pipe which can be closed by a cap and water lute when all has been displaced.

Absorbing Mixed Gases by Solids.—We may now pass to the problem of absorbing mixed gases by solids, or, rather, to be more accurate, of absorbing one or more gases from a mixture of several constituents. There are many instances of this class of operation to select from, but for our purpose they may be divided into two varieties, the first of which comprises those in which some particular gas is absorbed by the solid body without yielding anything material in return, such as when copper turnings are heated in a stream of air, giving oxide of copper as the result; or when a mixture of air containing chlorine is passed over the surface of hydrate of lime lying upon the shelves of a Deacon chamber. In the second class we have those operations in which a gaseous equivalent is liberated for every equivalent absorbed. In this class we have the preparation of bisulphite of lime, where SO_2 is absorbed and CO_2 liberated, and the Hargreaves salt-cake process, in which SO_2 , O , H_2O is absorbed and 2HCl liberated.

Active gases are generally spoken of as "dilute" when they are mixed with inactive gases. The gas evolved from a mixture of manganese and hydrochloric acid is usually called strong chlorine, while that made by the Deacon process is termed dilute chlorine, and the inert gases accompanying it exercise a greatly retarding action upon the absorption. This is so in all cases, and it has been found by experience that whereas 160 square feet of absorbing surface of lime is ample for the manufacture of manganese bleaching powder, per ton per week, no less than 500 square feet per ton per week are necessary for the manufacture of bleach by the Deacon process, or more than three times that required when strong chlorine is employed. In a Deacon gas, with which the author was at one time concerned, the (dilute) chlorine left the decomposer associated with 90 per cent. of inert gases, and yet the absorption was complete when a sufficient length of run was given to the gas, in the proportion already mentioned. More dilute chlorine than this has also been satisfactorily dealt with by the Deacon chambers. To the author's knowledge, as little as 23 grains mixed with each cubic foot of air has been removed completely. It should be mentioned in this

connection that the gases leaving the Deacon "decomposer" contain, as a rule, more chlorine than the proportion just indicated, but the multitude of joints, ever leaking air inwards, very considerably reduce the percentage before the absorbing chambers are reached.

A "Deacon" chamber for absorbing dilute chlorine consists of eleven series of two shafts each, or 22 shafts in all. Each shelf measures 20 feet in length by three feet nine inches in width, and there are sixteen shelves in each shaft placed at a distance of six and a half inches from each other. Each series of shelves packs out three tons of bleaching powder at a time.

There is a mechanical apparatus for the absorption of dilute chlorine, known as the Hasenclever chamber. It consists of a series of iron tubes through which lime is carried by a spiral conveyor, the gas passing in a contrary direction to the lime. The current of air, together with the radiating surface of the tubes, carry away the heat of the reaction, and the apparatus is quite satisfactory for dilute gases, though it is stated to be unsuitable for strong chlorine. It is not in use in any work in the United Kingdom.

Instead of passing the gases over the surface of the solid absorbent, they may, in some cases, be passed through a bed of it, as when crude coal-gas is put through a bed of hydrated oxide of iron or hydrated oxide of manganese in order to extract the sulphuretted hydrogen from it. If the absorbent will remain open after contact with the active gas, and provided that the heat of the reaction can be continually removed, this method is very effective; the only precaution to be taken is to ensure that the whole of the gas is evenly distributed over the area, and that no short cuts be left for it to take in preference. What thickness of layer may be safely introduced is only to be found by practical experience with each individual problem. For ordinary gas purifiers, Newbiggin gives the rule that nine square feet of effective grid area should be allowed for each 1,000 cubic feet passed per day, on the supposition that the layer of purifying material is placed three inches thick upon the grids. The thicker this layer is, the higher the back pressure or resistance must be as a matter of course, and this resistance is influenced by the nature of the bed of material and the volume of gas it is endeavoured to pass through the unit area of grid surface.

In some experiments made by the author several years ago to ascertain the volume of inert gas (air) that could be passed through a bed of sieved lime six inches in thickness under various pressures, it was found that per square foot of area, a pressure of three-and-a-half inches of water allowed the passage of one cubic foot per minute or 60 cubic feet per hour. Under a pressure of two-and-a-half inches of water, 40 cubic feet were passed per hour, while, with a pressure of four-and-a-half inches of water, 80 cubic feet per hour were passed.

In processes where an equivalent volume of a gas is evolved from the materials for each volume of gas absorbed, provision must, of course, be made for the escape of the gas that is given off, and the apparatus has to be arranged accordingly. In the Franke process of preparing wood pulp by means of bisulphite of lime solution, the bisulphite is prepared by acting on limestone with sulphurous acid gas (the gas from pyrites burners). The

limestone is placed upon shelves in a tall tower, and the dilute sulphurous acid gas passing up this tower converts the lime into sulphite and bisulphite, liberating the carbonic acid. Water is trickled down the tower, which constantly removes the crust of bisulphite, and so keeps the surfaces clean. It will be seen that the apparatus is exceedingly simple, but, as the lumps of limestone grow by degrees smaller, the internal construction of the tower must be such as will not allow of undue settlement, and will admit of easy access for refilling when necessary. This is why the tower is divided into a series of chambers by shelves, as it would not be workable to fill the tower with limestone in the way that muriatic acid towers are filled with coke. The carbonic acid gas that is evolved during the operation is allowed to escape through a short shaft upon the tower top. This illustration is merely given to illustrate a principle and not to show how bisulphite of lime is made. Except for the production of "sulphite" wood-pulp, the bisulphite of lime manufacture is not of any great magnitude in any individual works, and the sulphurous acid gas required is either produced by heating sulphuric acid with sulphur, or burning sulphur in a furnace of the kind already illustrated on page 116. In such cases, the lime in which the sulphurous acid gas is absorbed is made into milk of lime, and is kept in agitation by mechanical means while the gas is being absorbed in it. In the former instance the operation comes fairly under the head of absorbing pure gases by liquids, and in the latter case, the absorption of mixed gases by liquids.

In the Hargreaves process of making salt-cake, a mixture of pyrites gas (dilute SO_2) and steam is passed through heated salt in lumps about the size of ordinary road metal. Sulphate of soda is formed and hydrochloric acid gas evolved, which passes along with the current of inert gases, and is washed out in water towers. The Hargreaves process is an example of very slow chemical action. The reaction is not confined to the surface of the lumps of material, but has to be completed right to the centre of the mass, and this takes time. In a plant of which the author once had charge, 12 cylinders, each holding 37 tons of salt-cake, were drawn at the rate of three per week, so that the material was under process for about one month from the time of charging to that of discharging. The temperature required for energetic absorption varied between 430°C. and 520°C. , and when the temperature fell below 320°C. , the absorption ratio dropped to a very small figure.

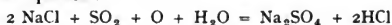
In the earlier days of this process, the fuel used under the cylinders at the Runcorn works amounted to nearly nine cwts. per ton of salt-cake, and at the new Atlas works in Widnes the figures given to the author by the late Mr. T. F. Moorhouse were six cwts. per ton. It has been argued that as the reaction is exothermic there should be no need for external heat, but a moment's thought will convince anyone that a cylinder commencing its journey at 200°C. , and ending it at 520°C. a month later, must necessarily lose a very considerable quantity of heat by radiation.

In the set of cylinders at the Runcorn works, when the process was working satisfactorily, the following conditions obtained :—

TABLE 18.
SHOWING THE ABSORPTION OF SO₂ BY NaCl.

Num ber of Cylinder.	Tempera- ture C.	% Absorp- tion.	Vacua in m.m. Water.	Abnormal.	
				% Absorption.	C.
1	538	Packing.	3'17	5'7	515
2	515	10'0	6'35	9'3	510
3	500	15'0	9'52	10'0	443
4	460	15'0	11'11	10'0	443
5	465	13'6	12'70	4'2	426
6	465	14'7	14'29	6'1	415
7	465	11'7	15'87	4'7	393
8	371	10'0	15'87	5'0	349
9	316	4'0	17'46	4'8	349
10	332	4'0	19'05	4'0	294
11	343	2'0	20'64	3'0	277
12	232	Heating.	22'22	1'0	—

The two last columns of the table headed " abnormal " will show the effect of insufficient steam. The nozzle of the steam-jet supplying the steam, to satisfy the equation :—



had been choked with a piece of the red-lead used in making the joints, and this was not discovered until pointed out by the bad absorption. The fourth column of the table shows the effect of friction, in retarding the flow of the 102,000 cubic feet of gases per hour in their passage through 120 lineal feet, or 19,360 cubic feet of baked salt broken to the size of average road metal.

It may be of interest to add, that the total cost for labour in working this process amounted to four shillings and ninepence per ton of finished salt-cake, from the taking of the raw salt from the stores to placing the finished salt-cake in the store shed.

Absorbing Mixed Gases by Liquids. — We have now to consider a problem in the absorption of mixed gases that differs from anything that has been treated of before. When dilute gases are brought into contact with solid absorbents, there is no difficulty in the way of complete absorption. Thus, in making bleaching powder with " Deacon " gas, the product, if properly handled, will contain as much active chlorine as if it had been made with manganese chlorine, but a very different state of affairs occurs when mixed gases are treated for absorption by liquids.

The earliest attempt to deal with problems of this kind seems to have been connected with the alkali trade. Prior to the Alkali Act of 1863, most of the hydrochloric acid gas liberated from the salt used in the manufacture of sulphate of soda was sent into the chimneys of the establishment,

and from thence into the atmosphere. Mr. William Gossage seems to have made the first determined effort to prevent this gas from escaping. In his works was an old windmill shaft; this he filled with gorse and brushwood, showered water in at the top, and passed the mixed gases in at the ground line—thus becoming the possessor of the first "condenser" for hydrochloric acid gas the world had seen.

It soon became evident, however, that bricks and mortar were hardly the correct materials from which to construct hydrochloric acid absorbing apparatus, and so the use of stone slabs, or as they are technically termed, "Yorkshire landings," came to be universally adopted. At first, various materials were employed for "packing" these towers (as the term runs for filling them with absorbing materials), but it was soon found that for acid substances hard Durham coke was the best that could be found. This system is the one generally adopted to-day, and is in use in every works wherein mixed gases are absorbed by liquids without the formation of a precipitate.

In the early days of the Leblanc industry, the salt-cake gases were hot and very dilute owing to the employment of open roasters. The temperatures at which the gases left the furnace were seldom less than $600^{\circ}\text{C}.$, and the author has seen them entering the absorbing towers at $260^{\circ}\text{C}.$, at $316^{\circ}\text{C}.$, and even at $370^{\circ}\text{C}.$ Moreover, the hydrochloric acid was very dilute, being mixed with all the products of combustion, as well as the extraneous air drawn in at the working doors during the time of raking the charge.

In those days, too, the gas issuing from the pot and that coming from the furnace were kept distinct, and passed to separate towers. The pot gas was made into strong acid of 32°Tw. , while in many cases the roaster acid was so weak that it was allowed to run away to waste. When the acid was collected from roaster towers it usually possessed a density of from 16°Tw. to 20°Tw. , and in some works was run into a series of stone cisterns, through which the pot gas was made to pass, on its way to the pot towers, after the manner of the receivers attached to the cylinder in making cylinder acid; by this means the weak acid was raised to 30°Tw.

The attempt to make strong acid from dilute gases called wash-towers into existence. These were towers generally packed with bricks (sometimes with large coke) through which the gases, nearly denuded of hydrochloric acid, were made to pass on their way to the chimney. Large volumes of water were poured down these towers, and the weak acid ran away from the outlet at all strengths from 1°Tw. to 5°Tw. In some works 8°Tw. acid was aimed at, and the weak acid was utilised in the preparation of carbonic acid for the manufacture of bicarbonate of soda. The wash-tower was often a source of serious loss in production.

All the intricacies of the past have, however, disappeared since the universal introduction of "close" or "muffle" furnaces, especially those of the plus-pressure-pattern, and to-day a furnace making 84 tons per week of salt-cake will need only one simple acid-making tower filled with coke, six feet square and 50 feet high, to condense—as it is still called—the gas produced by it. Wash-towers have been found absolutely unnecessary.

Usually the salt-cake gases enter the towers at about $66^{\circ}\text{C}.$, and leave at about $50^{\circ}\text{C}.$, while the solution of hydrochloric acid leaves the tower at about the temperature of the entering gases, or a little higher. Some very careful measurements of the acid produced per ton of 90 per cent. salt were made by the author several years ago, and resulted in the collection of 56 cubic feet, or 350 gallons at $30^{\circ}\text{Tw}.$, showing that the loss from all sources was under 4 per cent.

It was common knowledge, even prior to 1876, that certain gases would only give a certain maximum strength of liquid acid. Thus with pot-gas it was often $36^{\circ}\text{Tw}.$, while the more dilute roaster gas would only yield a maximum of about $20^{\circ}\text{Tw}.$ The "Hargreaves" gases of those days would only make an acid of $20^{\circ}\text{Tw}.$, but the reason of this was not generally appreciated until the late Dr. Ferdinand Hurter pieced up the scientific work that had been done by several investigators on the absorption of hydrochloric acid gas in water, and supplemented it with some valuable suggestions of his own. Dr. Hurter's paper, which appeared in the "Journal of the Society of Chemical Industry" for 1889, page 861, must be read in the original to be properly appreciated, and stands as an admirable example of how technical subjects should be taught.

Dr. Hurter, in the paper already cited, gives an instance of the condensation of hydrochloric acid in a "condenser," eight feet square and 40 feet high (1,280 square feet of cooling surface), in which the gas entered at $73^{\circ}\text{C}.$ and left at $60^{\circ}\text{C}.$, the acid flowing out at $80^{\circ}\text{C}.$ This acid, when cold, possessed a density of $25^{\circ}\text{Tw}.$, and he pointed out that in order to secure a $30^{\circ}\text{Tw}.$ acid the temperature of the condenser and its packing should not exceed $65^{\circ}\text{C}.$ Proposals have been made for artificially cooling the absorbing towers, so that a further extract from Dr. Hurter's paper relating to the foregoing tower may be of additional interest.

The "condenser" admitted, in two hours, 840 lbs. of HCl and 216 lbs. of steam; the air leaving the tower being three cubic feet per second, or 1,720 lbs. The water supply was 2,520 lbs. in the two hours, which entered at $15^{\circ}\text{C}.$

From these data, we have :—

(1) Centigrade heat units entering condenser :—

Air,	1,720 lbs. at $73^{\circ}\text{C}.$	Sp. heat 0.23	=	28,878
HCl	840 lbs. at "	" " 0.18	=	11,037
Steam	216 lbs. " "	" " 0.48	=	7,560
				47,475

(2) Centigrade heat units in gas leaving tower :—

Air, 1,720 lbs. at 60° C.	21,958
Steam 260 lbs. "	7,488
Latent heat of 44 lbs. steam	23,584
	<hr/>
	53,030



- | | |
|---------------------------------------------------------------------------------------------------------|---------|
| (3) Centigrade heat units generated within the condenser during absorption of HCl to 25° Tw. | 350,601 |
| (4) Centigrade heat units carried away by hot acid, flowing out at 80° C., the water entering at 15° C. | 149,674 |

If from the amount of heat generated we subtract that carried away by the hot acid, and that which the gas takes away more than it brings, we find that the condenser walls must have dissipated the remainder, viz., 195,282 units, or 76 units per square foot per hour. What we learn from this example, taken from actual practice, is that for successful condensation, it is necessary to provide ample cooling surface in that part of the apparatus in which the gas comes into contact with the absorbing liquid, since it is the act of absorption which generates the great amount of heat.

It is now possible to predict the strength of the liquid hydrochloric acid that can be made at any given temperature, from any mixture of gases, with absolute certainty. Hurter's conclusions, on the absorption of mixed gases containing hydrochloric acid, may be summed up in a few words:— Employing strong gas, *i.e.*, limiting the inert gases as much as possible; cooling the gases before absorption; and cooling the liquid in which the active gas finds solution.

Coke packing has been mentioned as suitable for acid solutions, and, indeed, coke is hard to beat, but crinkled glass, vitrified clay rings, hollow balls, and other materials have been proposed and used instead. As early as 1870 special white porcelain blocks were in use for roaster towers, but these have now disappeared. For sulphuric acid absorbing towers, the packing material is generally coke, but the other forms of material mentioned above are also employed.

The illustrations on page 205 show a variety of forms of tower packings produced by the manufacturers of chemical stoneware, and probably some of these have advantages over the others, but in the absence of definite large scale experiments under fixed conditions their relative efficiency is by no means a fixed quantity. Some of them have been compared with the ordinary coke packing of the well-known absorbing towers, but this is scarcely permissible for a critical comparison, as the author is strongly of opinion that the ordinary coke packing of muriatic acid towers, or vitriol absorbing towers, and even of many denitrating towers, has in the past been done in a very rule-of-thumb fashion. If the coke had been carefully broken to a moderate size, freed from dust and adhering small particles, and properly sized, there is no doubt the ordinary coke scrubber would have been able to give a better account of itself, but packed as it often is with lumps 18 inches long by six inches or eight inches square, how can it be expected to compare with packing, say, of three-inch spheres?

If we consider the wetted surface of the packing material to be the active agent in absorption, it would seem better to pack all such towers with

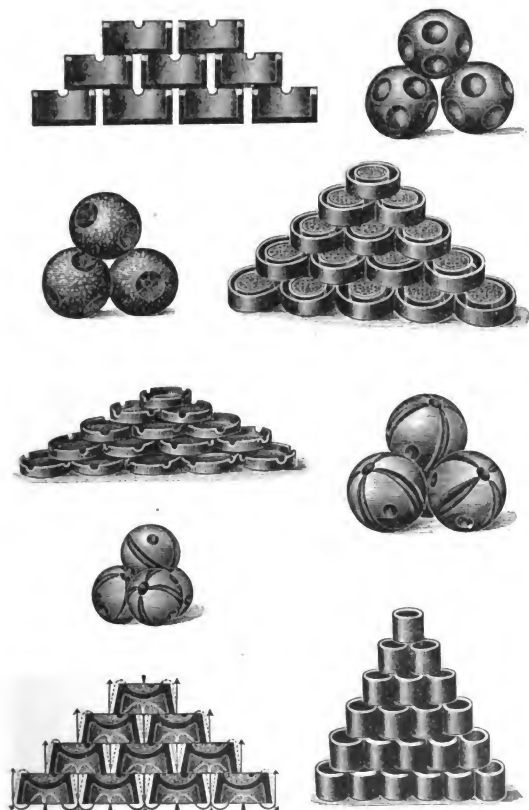


FIG. 96.—VARIOUS FORMS OF TOWER PACKINGS.

material that would give the greatest surface, and this is just as true of coke as of any other packing material. In packing towers with coke, however, its feeble resistance to a crushing stress must be taken into account, but it is very probable that three-inch fragments would bear whatever stress is likely to be placed upon it, while it is more than probable that towers packed in this way would not need to be so high as the present coke-packed towers are built. We have only to consider one special case from practice to show how much there is to learn yet with reference to coke-absorbing towers. At a works known to the author, where sulphuric acid was rectified in one of the newer forms of plant, dense white fumes were emitted from the acid in the concentrating apparatus, which a water-tower, 20 feet high, packed with large coke, absolutely refused to stop. This coke measured about 12

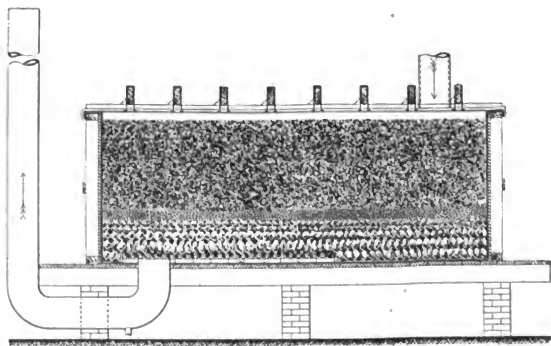


FIG. 97—KESLER'S CONDENSER FOR SULPHURIC ACID FUMES.

inches long by six inches square. The vapours were then turned into a tower 30 feet high, packed with smaller coke (approximately six inch cubes, with a large proportion of considerably smaller fragments), and the result was decidedly an improvement, though by no means satisfactory.

Let us now contrast the foregoing mode of operating with that of the "condenser" attached to the Kessler concentrating plant, a full description of which will be found in Chapter IV. The construction of this condenser may be seen in Fig. 97. It is of considerable area and small depth, and the coke with which it is packed is carefully graded in several sizes. These sizes are so small in dimensions that were it not known to be actually in use in several establishments one would hesitate to accept its practicability. The draught is downwards, the gases entering at the top, and the liquid produced running out from below the coke packing. Upon a grid which supports the coke and allows of the escape of the waste gases, a layer of large coke is placed; upon this is a layer of 2 in. pieces, then a layer of $\frac{1}{2}$ in.

pieces, while the whole of the remainder is composed of coke that will all pass through a one-eighth of an inch screen, and yet be retained upon one of a one-sixteenth of an inch mesh. This is clearly shown in the illustration.

An examination of the amount of surface presented to the gas by such small fragments of coke is most interesting. If we suppose the particles to be spheres, one-twelfth of an inch in diameter, a cubic foot of them in regular pile would number more than three millions, and as each one would present a surface of 0.0216 square inch the three millions would possess a surface of 451 square feet, or more than fifty times the surface than if the coke had been filled in, in the usual large pieces. We may pursue the investigation a stage further; a single layer of such spheres would contain 20,736, and, as the sectional area of each one is 0.0055 square inch, the proportion of a square foot actually covered is 0.79, leaving 0.21 square foot for gas room. In practice, the actual gas room would be less than this, as there would be a layer of liquid adhering to each sphere, but it has been abundantly shown that in the Kessler condenser there is not only ample room for the condensation of the acid fumes, and the steam from the jet producing the draught, but also for the whole of the products of combustion arising from the coke used for the concentration. Nevertheless, the proportions of such a "condenser" require to be scientifically adjusted, and it is quite possible that a rule-of-thumb trial would prove a failure.

If now we can reckon the surfaces that can be packed into one cubic foot of tower space by the use of various packing materials, such numbers may give some idea as to their relative efficiency: These numbers are:—

Three-inch bricks with $1\frac{1}{2}$ in. spaces	5.6 sq. ft.
Large coke	8.5 "
Three-inch solid clay balls	12.5 "
Four-inch clay tower rings	16.3 "
Half-inch boards with $\frac{1}{2}$ in. spaces	24.5 "
One twelfth of an inch spheres	451.0 "

From the foregoing figures, it would appear that the tower rings should be twice as efficient as coke, and three times as efficient as full-sized bricks.

The relative efficiency of the various forms of packing is still open to discussion, owing to the varying conditions under which such apparatus is worked, but the author has determined the relative efficiency of coke *versus* full-size bricks to be about two to one from the following experience:—In a plant designed to burn spent oxide, two absorbing towers filled with vitrified bricks—set in pigeon-holed fashion—were provided to arrest the nitrous compounds, and these only just performed the work required of them. Then a change occurred, pyrites were substituted for spent oxide, the bricks were taken out of the absorbing towers, and their place filled up with coke, when it was found that one tower so packed arrested as much nitrous gas as the two towers had done before. This was an experience extending over many months, and well watched.

Sometimes, however, coke could not well be employed. Coke is a good filter and would arrest any solid particles sent over it, which would choke the interstices, and so stop the passage of gas. This is why coke could not

be used in the filling of a de-arsenicating tower, and was also the reason why a brick packing was employed in the absorber of a spent oxide sulphuric acid plant. Chamber acid of 123° Tw. made from spent oxide with a denitrating column is as free from ferrous sulphate as is pyrites acid, but the acid running from the denitrator is saturated with this salt at the temperature at which it leaves the apparatus, and, when cooled down, this sulphate is thrown out of solution. Owing to the viscous nature of the acid at 150° Tw. the ferrous sulphate does not immediately settle out, but on passing such acid down the absorber, the coke would most effectually filter out the iron salt, choking the tower up in time. It must not be forgotten that coke absorbs about 80 per cent. of its weight of the absorbing fluid, when that is oil of vitriol, so that the emptying and refilling of an absorbing tower is a serious matter, and should not be undertaken except upon the most convincing proofs of its necessity.

When neutral or alkaline liquids have to be dealt with, the absorbing apparatus is easier of construction, and may be filled with a greater variety of absorbing material. In gas-works practice, a cast-iron circular column filled with boards or canvas screens, set on edge, form the absorber. It is called a "scrubber," and answers the same purpose as a coke-tower, but when tarry matters are present in the gases, coke will not remain long without requiring to be thoroughly cleansed, which is not an easy operation.

One advantage which the coke tower has over most other forms of absorbing apparatus is the large volume of gas which may be transmitted through a comparatively small area without undue friction, and in many cases there is no need for even a chimney draught, as the temperature of the gases, and the height of the tower, will serve all the purposes of a chimney.

Professor Lunge has shown us that the interior of an absorbing column may with advantage be packed with a series of perforated plates in lieu of coke. These plates are carefully made so that a thin layer of liquid surrounds the perforations, and gradually the liquid finds its way from plate to plate, becoming strengthened by absorption at each successive movement downwards. In these plates, the holes are from 6 millimetres to 7 mm. in diameter, and there are about two holes in each square inch. Lunge states in his "Sulphuric Acid and Alkali," Vol. II., p. 384, that a tower of 60 plates 26 inches in diameter, will serve for condensing the hydrochloric acid from five tons of salt per 24 hours, and that a column 2 ft. 8 ins. in diameter will suffice for 10 tons per day, which is equal to the produce of one plus-pressure salt-cake furnace. If we allow two perforations in each square inch, this would give 1,608 holes in each plate, and if each be 7 mm. in diameter, the combined area of the perforations in each plate would be 80 square inches, or equal in area to a pipe 10 inches in diameter. In order that the construction of these plates may be thoroughly understood, the author has reproduced, on a reduced scale, a sketch of a portion of one of them (showing the upper and under sides) from Prof. Lunge's work already mentioned. These may be seen in Figs. 98 and 99.

Mr. H. H. Niefenführ, of Berlin, who has had much experience with these Lunge towers, has kindly supplied the author with some details

and ideas that may be of interest to the reader. It has already been mentioned that the chamber process of vitriol making is really one of absorption, and this is borne out by Mr. Niedenführ's remarks. He informs the author that from the experience gained with plate towers it is quite possible to replace the lead chambers entirely by Lunge columns, only it must be borne in mind that the construction of the front parts of the system must cause as little loss of draught as possible, and the resulting heat of formation and dilution must be withdrawn in a corresponding degree.

Fig. 100 shows a sectional illustration of a part of a Lunge plate, and, as the perforations thereon exhibited possess only a diameter of 7 mm., it will be seen that a comparatively large sectional area must be given to the towers, and in order to prevent the heat of the reaction from doing



FIG. 98.

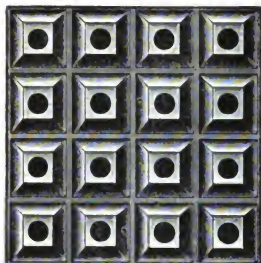


FIG. 99.

SHOWING THE UPPER AND UNDER SIDES OF THE "LUNGE" PLATES.

damage, a uniform, complete and heavy flow of liquid must take place down the towers.

The plates used in the construction of sulphuric acid towers are 610 mm. square (2 ft.). These are grouped together to form layers, in numbers depending upon the area of the cross section of the tower, each layer being separated from the next by an interval of 125 mm. (5 ins.), a distance which is called a "single interval." When the plates are placed at 250 mm. apart (10 ins.) it is called a "double interval." Mr. Niedenführ has found that when burning one ton of sulphur per 24 hours, the number of plates in each layer required per 100 kilos. of sulphur burned amounts to 1.2 plates in the foremost part of the system, 1.0 in the middle portion, and 0.6 in the last portion; but in burning five tons of sulphur per 24 hours 0.6 plate will serve for the foremost portion, 0.5 plate for the middle, and 0.4 for the end of the series.

The number of layers of plates which must be employed for a given production is calculated as follows:—If the layers in the first third of a system be arranged with triple intervals, we may assume a yield of 10

to 12 kilos. of monohydrate for each plate that is used. In the second third the layers would be at double intervals, and each plate would yield 6 to 8 kilos. of monohydrate; while in the last portion of the system, with the layers at single intervals, 1.25 to 2 kilos. of monohydrate would be produced from each plate.

Another process, depending upon a preliminary oxidation before absorption, may be instanced in the interception of nitrous vapours and the recovery of the nitric acid produced. This is brought about in several industries, such as the manufacture of arsenic acid, nitrate of iron, in the denitration of the waste acids from the process of nitrifying various organic substances, and in the method of producing chlorine by means of nitric acid. In all these processes oxides of nitrogen are disengaged, and their transformation into and recovery as nitric acid is an economical factor.

Notwithstanding all that has been written on the subject, the recovery of strong nitric acid has not been satisfactory in many works where it has been attempted. It is by no means difficult to recover the acid at

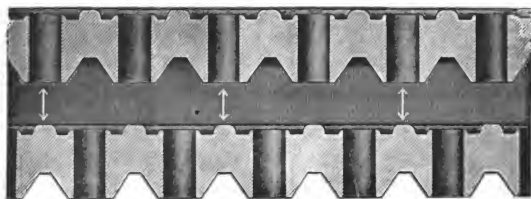


FIG. 100.—SECTION THROUGH A LUNGE PLATE.

gravities of 1.15 to 1.20, but when we come to a specific gravity of 1.42 to 1.5 the task is not found to be an easy one. Lunge and Pelet have studied the combined action of air and water upon nitrous vapours, and have come to the conclusion that 94% of the oxides may be converted into nitric acid. The absorption apparatus with which they experimented consisted of two empty flasks surrounded with ice, followed by six washing flasks containing water and lastly any vapours that escaped were taken through an intercepting vessel charged with potassium permanganate. It was found in one of the experiments that as much as 51% of the regenerated nitric acid was found in the first flasks and 30% in the first washer, the remainder being found in the five later washers and 2.73% in the permanganate interceptor. In all 98% was recovered. These results may be easily repeated on the large scale when working with dilute solutions, but as one approaches the gravity of the mono-hydrate so the difficulties increase.

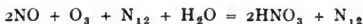
At one work formerly inspected by the author, the nitrous vapours evolved from the manufacture of nitrate of iron were mixed with air and passed through a series of 80 Wolff bottles (Fig. 92) containing water,

the recovered acid being drawn out of the front jars at 34° Tw. to 36° Tw. The labour of changing the acids in the jars was very great, but had they been of the pattern shown on page 118, Vol. I. this would have been avoided. At a neighbouring works a similar manufacture was carried on, but the gases were mixed with air and steam and passed in series through four earthenware towers packed with coke. The towers were 2 ft. diameter and 16 ft. high, and the acid was obtained from them at 36° Tw. to 40° Tw.

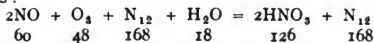
In the nitric acid chlorine process the author employed a series of earthenware towers, each 2 ft. 6 ins. diameter and 14 ft. high, packed with pumice in lumps about the size of a hen's egg or a golf ball, but using these alone he was not able to secure a regenerated acid stronger than 50° Tw., and even this strength required the utmost care. At the outset six of the aforesaid towers were employed, and there proved to be no difficulty whatever in condensing 93 per cent. of the vapours when acid of 40° Tw. was aimed at, but in endeavouring to raise the acid to a higher specific gravity more towers had to be added. When working with six towers only, 62 per cent. was collected from the first tower, 15 per cent. from the second, 7·0 per cent. from the third, 5·0 per cent. from the fourth, while the fifth and sixth towers yielded 4·0 per cent. The temperature of the gases entering the first tower was 104° C., and there was 8·0 per cent. of oxygen in the gases leaving the last tower.

The endeavour to produce stronger acid by coupling up more towers in series was not wholly successful, as a series of twelve towers only produced an acid of 60°—65° Tw., and there were frequent disturbances for which no reason could be assigned, and this led the author to the conclusion that he was not following the correct method, and that the pumice packing with which the columns were furnished was rather detrimental than otherwise during the first stages of absorption. This was apparently proved by the fact that it was ascertained that other works were producing acid of a higher specific gravity, in condensing tubes, without the intervention of any packing whatever.

Let us now examine what takes place when nitric oxide is converted into nitric acid by means of air and steam. The reaction may be expressed as :—



The heat of this reaction being 57,400 C.H. units for each 126 parts of nitric acid produced, and the gases entering the system at a temperature of about 100° C., it will be seen that there is a considerable quantity of heat to be dissipated before cool liquid nitric acid can be collected. We may easily find what it is :



Let us call the foregoing combining numbers pounds, and remembering that a large excess of air is more often than not admitted into the system, we may admit that double the volume of air theoretically necessary has been employed. We shall find then that :

				C.H. UNITS.
60 lbs. nitric oxide at 100°C.	sp. heat	·2317	=	1,390
48 „ oxygen „	„	·2175	=	1,044
168 „ nitrogen „	„	·2438	=	4,096
18 „ water „	617 C.H.U		=	11,106
216 „ air „	sp. heat	·238	=	5,140
Heat of the reaction				57,400
				80,176
126 lbs. nitric acid	at 20° C. sp. heat	·445	=	1,121
168 „ nitrogen	at 20° C. „	·2438	=	820
216 „ air	at 20° C. „	·238	=	1,028
				2,969

If now we assume that one square foot of *thin* earthenware pipe 4 ins. diameter will dissipate 150 C. H. units per hour, there would be required :

$$\frac{80,176 - 2,969}{150 \times 126} = 4.0 \text{ square feet}$$

of pipe surface for each pound of real nitric acid (HNO_3) per hour, from which the necessary cooling surface for any installation may be found.

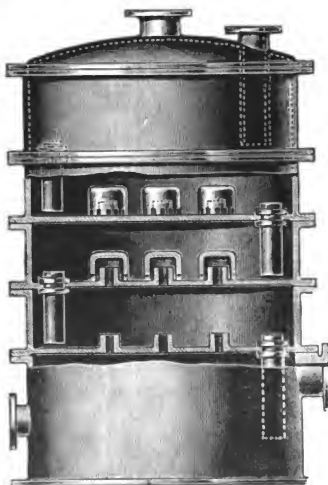


FIG. 101.—GAS WASHER.

This ratio only holds good for *thin* earthenware surfaces ; if ordinary thick acid pipes be employed, the surface indicated by the calculation should be doubled or even trebled, according to the thickness of the walls.

The foregoing cooling surface of a pipe range is not sufficient to intercept the whole of the nitrous vapours passing into it, so that it is still necessary to supplement it by an absorption tower filled with Lunge plates or any of the filling materials already mentioned. If pumice or broken glass be employed for this purpose, they should be used in much smaller pieces than is generally the case. A recovery plant to produce 40 tons per week of nitric acid of 80° Tw. from the oxidisable oxides of

nitrogen will cost about £1,000, exclusive of connections, foundations, brickwork, buildings, etc.

The Lunge plate tower occupies a position midway between the coke tower on the one hand and what are called washers on the other, inasmuch as the coke tower requires the minimum of "head" to overcome friction, while washers—in which the gases are made to bubble through the "washing" liquid—require head sufficient to overcome the water seal.

Washers, in which the mixed gases are forced through a certain depth of the absorbing fluid, are of many patterns and designs. It is not necessary to go through any list of these appliances, as the principle can be just as well explained by means of one of the simplest of its kind. This form may be seen in Fig. 101, which shows three shelves, one in section, one in elevation, and the third deprived of its gas caps.

The wash water, or absorbing liquid, enters the apparatus at the top, and passes down from tray to tray, finally leaving the lower chamber, which must be sealed so as to prevent the escape of gas there. The gases enter at the side, and passing through the orifices on each tray, find their way through the serrations of the bells covering them, and so on from chamber to chamber until the unabsorbed gases pass out by the aperture at the top.

Fig. 102 is a section through a washer with one bell only, and is given to show the principle upon which the apparatus operates.

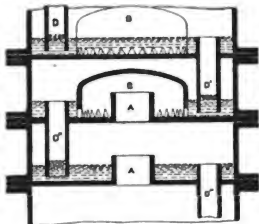


FIG. 102.—GAS WASHER (SECTION).

The absorbing liquid passes down the washer from tray to tray, by means of the pipes D, D', D'', and D''', and it will be seen that the top edges of these pipes are placed so as to give a constant depth of liquid lying upon each tray. The lower ends of these pipes dip into this layer of liquid, and so prevent the gases from passing up them. The gases pass upward from the underside of each tray through the orifice A, and leave the underside of the bell B by means of the serrations, bubbling through the depth of liquid determined by the height of the top edges of the pipes D.

It is, of course, a *sine qua non* that the serrations be totally submerged when the washer is working, and the lower end of the pipes D must be effectively sealed with the liquid, as the unsealing of even one of these pipes will completely upset the working of the apparatus.

Some very interesting figures of the relative value of washers and scrubbers were obtained by the author when in charge of a carbonising works near Barnsley. The plant carbonised 50 tons of coal per day of 24 hours, the gas from which, after passing through a horizontal air condenser, was taken through two scrubbers placed in series. In the base of each of these scrubbers (which were 8 ft. in diameter and 40 ft. in height) were

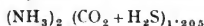
placed two trays of washers as in Fig. 101, the 36 ft. of scrubber above them being packed with timber filling of the usual pattern. Some very careful tests were made during the normal working of these washers. The volume of water used down the weak scrubber was just the quantity required to feed the strong scrubber and yield a liquid of 7° Tw. The gas entering the strong scrubber washer contained 1,362 grammes of ammonia in each 10,000 cubic feet. It left the washer containing 721 grammes, and at the top of the strong scrubber the gas only contained 4·6 grammes per ten thousand cubic feet. Of the total ammonia presented to the apparatus, the absorption was :—

	Per cent.	Grammes per 10,000 cu. ft.
By the washer	47·00	641
By the scrubber	52·66	716
Passing to weak scrubber	0·34	5
	<hr/> 100·00	<hr/> 1,362

The foregoing figures show clearly that the scrubbing power was ample for at least 100 tons of coal carbonised per day, as the weak scrubber had practically no work to do. It was therefore determined to utilise the excess of capacity in making the liquor stronger, and only water sufficient to make 10° Tw. in the strong scrubber effluent was used down the weak tower. While this was going on satisfactorily, a test was made extending over 53 hours, the inlet gas containing 1,746 grammes of ammonia per 10,000 cubic feet. While working at this high strength of liquor, the gas leaving the washer chamber was found to contain 979 grammes per 10,000 cubic feet, while the unabsorbed ammonia passing away from the top of the strong scrubber and entering the weak scrubber amounted to 350 grammes per ten thousand cubic feet. Tabulated, this means :—

	Per cent.	Grammes per 10,000 cu. ft.
Absorbed by washer	43·90	767
Absorbed by scrubber	36·10	629
Passing into weak scrubber	20·00	350
	<hr/> 100·00	<hr/> 1,746

It may be of interest to state that the volatile ammonia compounds in the 7° Tw. liquor corresponded to the formula :—



while the liquor from the weak scrubber, usually 1½° Tw., corresponded to :



showing that over and above the carbonation the liquor was holding free CO_2 or H_2S , or both, in solution.

In a paper read before the Liverpool Section of the Society of Chemical Industry in 1885 by the late Dr. F. Hurter, "On the comparative efficiency of the various methods of treating liquids with gases," there will be found

some very important information upon the subject we are now considering. The problem was however attacked by Dr. Hurter from another point of view, viz. : passing the gas divided into small bubbles through a comparatively deep column of the liquid, as in the oxidiser of the manganese recovery process. When operating in this manner it was found that the velocity of the bubbles, from the delivery orifice to the surface of the liquid (water), was practically constant with various depths of liquid.

A current of gas may be sent through a liquid in three distinct ways. First, it may be forced into the liquid contained in a vessel open to the atmosphere. By a second plan, the vessel may be closed in at the top and the gas drawn through by a vacuum pump; while the third method consists in closing the vessel and allowing the exit gas to escape under the pressure of a loaded valve. Dr. Hurter's calculations for 13 ft. depth of liquid show that the first method is the cheapest of the three, and taking this as = 100, the various results compare as follow :—

1. In open-top vessel	..	..	..	100
2. By vacuum	..	..	..	72
3. Under extra pressure	..	..	..	36

In a further paper in 1887 Dr. Hurter showed how a good distribution of the gas over the area of the absorbing vessel might be effected, and instanced cases in which the gaseous current was divided by a perforated plate or false bottom such as was at one time employed for causticisers working by air agitation; by distributing pipes as was at one time usual in manganese oxidisers, and by serrated cones (Fig. 102) and perforated coils, which find employment in many chemical operations. Theoretically, no doubt, it is well that the gaseous current should be finely divided, and perhaps this is a necessity where the depth of the absorbing liquid is small, but with 13 ft. of liquid such as exists in a manganese oxidiser, a very minute division is not necessary. In large vessels and with a long traverse for the streams of gas, small bubbles coalesce to form large masses of air, the tendency to which increases with the volume injected, so that the bubble theory no longer holds good. The author's belief in the necessity for minute subdivision of the air injected into the manganese oxidiser once received a rough shaking. The distributing pipes on the bottom of the oxidiser required cleaning out, and they were consequently removed from the ten-inch air main that supplied the blast. Not knowing the exact length of time the cleaning would occupy, it was arranged to run the oxidiser without them for the whole of the ensuing week if possible, and the result was so satisfactory that they were never replaced. There was not the slightest difference that could be detected in the results, whether the distributing pipes were employed or not. Though this may be the case with columns of liquor of considerable depth, it is certainly not so with layers of absorbing liquids having a depth of only a few inches. In such instances the subdivision of the gas must be carried to the extreme limit, and this cannot be better effected than by the apparatus shown in Fig. 101.

The author's experience has been that it is wrong in practice to attempt the absorption of gases (from a mixture of gases) by passing

them through deep columns of liquid. In such cases it is almost impossible to have a perfect counter-current, and the result is an absorption efficiency gradually decreasing during the whole time of the operation. By using the gas washer shown by Fig. 101, the nearly inert gas comes into contact with fresh absorbing liquor, while the nearly saturated liquid leaves the apparatus in contact with the strongest gas. Working with fuel gases for carbonating the crude soda solutions in an alkali works, Dr. Hurter found that from 40 to 50 per cent. of the carbonic acid could be absorbed under a column of 6.5 feet in depth, but the author has shown on page 214 that a washer of two trays, each being sealed with *one-inch* of water, not only absorbed 47 per cent. of the ammonia present in crude coal gas, but also the carbonic acid equivalent to it, from a mixture containing only 2.0 per cent. by volume of CO_2 .

Washers of the class shown by Fig. 101 require power to force the gases through them. The amount is small, however, as a depth of liquid of one inch on each tray (effective) is quite sufficient, a series of six trays being about equivalent to nine inches of water pressure. There are instances in which even this pressure cannot be allowed, and this can be overcome by the introduction of spray or film washers, generally styled mechanical washers.

The Porion evaporating chamber, which is illustrated and described in the next chapter, is an excellent gas washer. It consists of a chamber about 40 feet in length, and of a cross sectional area corresponding to the work it is required to do. A layer of from eight to 12 inches of water or other liquid is maintained upon the bed of this chamber, and from this the spray is raised. Two sets of "fanners" are made to revolve at high velocity above the water layer, and they are so constructed as to slice off a section of about 3 mm. at each revolution, and project it into the atmosphere of the chamber as spray. When the fanners are working, the interior of the chamber is completely filled with an imitation of the most perfect and violent rain-storm ever seen, and through this the gases are made to travel.

The Porion system of spray producing is not universally applicable, but where it can be employed it deserves consideration. It has often been said that the spray system of treating gases is not an effective system, and is moreover more costly than most other plans. When the spray is clumsily produced this may be so, but let us see what the Porion will do.

A chamber measuring 40 ft. \times 6 ft. \times 6 ft. requires a 5 I.H.P. engine for driving the fanners. Into a chamber of this size the products of combustion from 25 tons of coal have been turned weekly, with the result of washing out every trace of sulphurous acid from the gases. If we reckon 300 cubic feet of air per pound of fuel we shall find that the volume of gas passing through the chamber is 100,000 cubic feet per hour. Let us now see what power is required to inject this volume of gas into the manganese oxidiser. Taking the particulars given of the blowing engine on page 34 of Vol. I., together with the formula on page 309, we shall find that

$$\frac{2 \text{ R A S P}}{33,000} = \frac{2 \times 531 \times 17.8 \times 30 \times 4}{33,000} = 68 \text{ I.H.P.}$$

It has been already mentioned that the engine takes in 56 cubic feet of air at each revolution, which at 30 revolutions per minute is 100,800 cubic feet per hour. The difference between 5 I.H.P. and 68 I.H.P. is a margin of possibilities, but the relative efficiency of the Porion chamber as an absorber has yet to be ascertained.

The manufacture of sulphuric acid by the chamber system might well be considered as a spray absorption, but the spray instead of being produced mechanically is introduced as a jet of steam, or a spray of water. The temperatures of the chambers are always well below the boiling point of water, and the contents exist as a series of rain drops which are moved about by the current of gases passing through them. In a set of three chambers working normally the leading chamber contents will possess a temperature of about 80° C., the second 60° C., while the third or last chamber will have a temperature of about 40° C., unless, as sometimes happens, too much steam is being used in it, when the temperature may go up to 54° C., and the Twaddell go down to 80°, or even less. Both the temperature and the excess of air and steam will leave their mark on the working of the process.

We may now pass on to film absorbers, in which the film is produced by mechanical appliances. Film absorbers have for many years been employed in the gas industry, under the name of rotary washers, but the author is not aware of any machine of this type employed in the chemical industry proper. It is true that what are called rotary washers are sometimes to be found in manure establishments, and though possessing some similarity to those mechanical washers about to be described, yet they differ from them sufficiently to be placed outside the line of classification.

Mechanical absorbers were devised to present a large absorbing surface to the current of gas without producing or requiring pressure as applied to the gas itself, and in this respect their action is perfectly satisfactory. The construction of the mechanical absorber is generally that of a chamber through which the gas passes, a certain amount of absorbing liquor lying upon the floor of the chamber. A number of plates, brushes, discs, or other film carriers are made to revolve slowly in this chamber, and at the same time to dip into the absorbing liquid lying upon the floor. These film carriers become wetted in their passage through the liquid, and when they reach the stream of gas the film absorbs the active constituents, which are washed off into the liquid below as the film carrier revolves. When several carriers revolve, each dipping into separate liquor chambers, the process is converted into one of stage absorption.

A good example of the mechanical absorber may be found in Holmes' "scrubber-washer," which is used for the extraction of ammonia and other impurities from coal gas. It consists of a cylindrical vessel containing a number of circular discs studded with the fibres of Brazilian bass, so that they resemble huge flat annular brushes. These brushes press tightly against the faces of each section of the scrubber, in such a manner that the gases are obliged to pass through the fibres, which are constantly being

moistened by their passage through the washing liquid, which nearly half fills the vessel. There is a Holmes scrubber-washer in work at the Kendal Corporation gas-works. It was alluded to by Mr. T. N. Ritson, in his presidential address to the members of the Manchester District Institute of Gas Engineers, in February, 1900, in the following words :—" The washer in operation at Kendal has a gross volume of 254·4 cubic feet, and is capable of dealing with half-a-million cubic feet of crude gas per diem. So far, it has efficiently dealt with 336,000 cubic feet, with an average production of

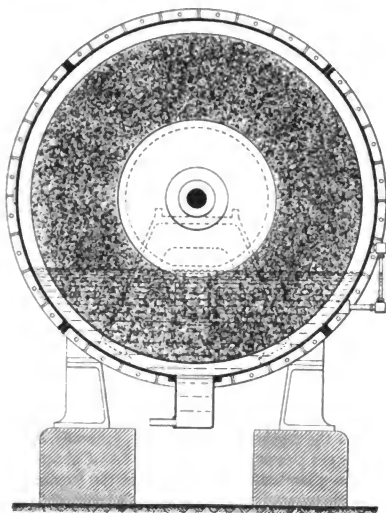


FIG. 103.—NEILL'S MECHANICAL WASHER.
(Messrs. W. Neill and Sons, St. Helens.)

' 29 ounce ' liquor, using from eight to nine gallons of water per ton of coal carbonised. The small quantity of ammonia (0·48 to 0·50 grains per 100 cubic feet) in the exit gases, and the fact that the liquor is fully saturated with carbonic acid and hydro-sulphuric acid, satisfies me of the efficiency of the machine."

A rotary mechanical washer is also applied by Messrs. W. Neill and Sons, of St. Helens, for the purpose of extracting the cyanogen existing in crude coal gas as an alkaline ferro-cyanide. The crude gas, after leaving the condenser, is made to pass through a long chamber divided into 12 or more compartments, in each of which is a continuous film-producing appliance.

The absorbing liquid, or magma of sulphide of iron and carbonate of soda, lies in the bottom of each chamber, and is gradually moved forward from one end of the washer to the other, while the gas passes in a contrary direction. The film carriers dip into this magma, and carry some of it round with them, and thus put it into intimate contact with the gases that are passing through. It is not necessary here to describe the reactions that take place further than to say that the hydrocyanic acid or the ammonium cyanide, is transformed into sodium ferrocyanide and other matters in solution and suspension, which find their way out of the washer in due course. The crude gas contains about one and a quarter grains per cubic foot of cyanogen, but the action of the washer is so perfect that less than one-eighth of a grain is found in the escaping gases, and even this quantity could be removed if the number of absorbing chambers were increased. It is obvious that washers or absorbers of this type may be put upon very variable work, regulating their capacity by the speed of the revolving discs.

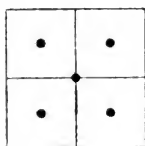
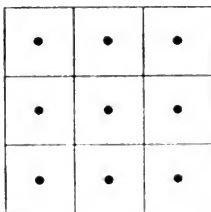


FIG. 104.



• FIG. 105.

Before leaving this subject of absorption, attention must be called to the means employed to keep all absorption surfaces wetted. In the washer proper, shown by Fig. 89, a constant level must be kept in order that the triangular serrations may be always sealed, and with mechanical absorbers the surfaces must be revolved, the liquid lying practically still. With spray producers, the necessity of maintaining a constant liquor-level is at once manifest, and it does not much matter how the water or other washing liquid is introduced in all these systems. In all tower systems, however, packed with coke or other filling material there must be an even distribution of water over the tower top, and there are many ways of doing this, some satisfactory, but many decidedly unsatisfactory. In no department of Chemical Engineering is there more need for the study of detail and cleanliness than in this apparently simple operation. If we go to the distributing floor of the absorbing or denitrating towers of any one of the numerous sulphuric acid works in the country, and examine the distributing arrangements, shall we not find the "piano," as it is called, the "Barker's mill," or other appliance partly choked with sulphate of lead, and only half the number of pipes running free into the tower? This is what it used to be when the author visited the works as an Inspector under the Alkali Acts, and if such

things have disappeared nowadays the managements are to be congratulated. The author's opinion is that the numerous pipes for distribution upon tower tops are an utter mistake. Sixty-four pipes upon a denitrating tower 8 ft. 6 ins. square, and 144 pipes upon an absorbing tower 12 ft. square, are often to be found even now—it is one man's work to attend to them properly, for if they are not *all* running those choked up may just as well not be there.

By the author's system, five distributors only are necessary for a denitrator and nine for an absorber of the foregoing dimensions, which should be arranged as shown by Figs. 104 and 105.

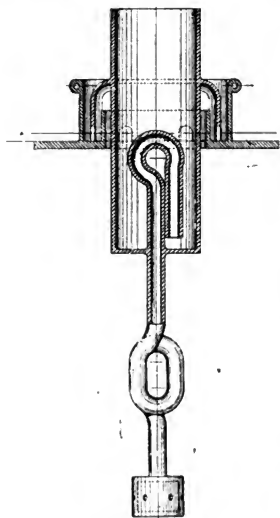


FIG. 106 —
THE AUTHOR'S AUTOMATIC DISTRIBUTOR.

The distributor itself is shown in Fig. 106, and consists of a circular cylinder of 7-lb. lead, 4 in. diameter, and 12 in. deep, into which is burned the syphon tube, as shown. The cylinder stands in a liquor lute, so that it may be readily removed if required. The syphon tube is prolonged from the underside of the cylinder, and projects, as a matter of course, into the interior of the tower, and the extreme end of the pipe is attached to a small circular box, closed at the top and bottom, and perforated with eight holes in the periphery. In order to prevent the entrance of air at the moment the syphon has completely discharged, the tube dipping into the tower is bent upon itself so as to form a seal. The full bore flow that takes place with this distributor insures freedom from chokeage, and the satisfactory character of the distribution must be seen to be appreciated.

Compressing Gases. — The principle of gas compressing is easily understood, as it is only complicated by the thermal effects due to change of volume, which can always be predicted with accuracy. Whenever a volume of gas changes its dimensions there is always thermal disturbance, the gas giving out heat during compression, and absorbing heat on expansion. The former effect may be observed during the working of an ordinary air-compressor, as shown on page 450, Vol. I., while the latter effect occurs in the production of cold illustrated on page 133 of this volume. When a gas is highly compressed, the heat evolved is considerable, and what has already been said upon the subject of compression during refrigeration may be read again with profit in this connection.

If we know the pressure to which the gas is to be subjected, the ratio $\rho = \frac{C_p}{C_v}$ which is the specific heat of the gas under constant pressure divided by the specific heat at constant volume, we can easily calculate the temperature that will be reached during compression, if all the heat liberated be retained in the gas. We shall also know what provision should be made for water cooling.

The temperature ($t^\circ \text{C.}$) to which a gas will rise by compression may be found from the following formula :—

$$t^\circ \text{C.} = \left\{ \left(\frac{p}{P} \right)^{\frac{\rho-1}{\rho}} \times (273 + T) \right\} - 273 \quad (a)$$

where P = the absolute atmospheric pressure, however expressed, ρ the specific heat ratio, T the atmospheric temperature, and p the absolute pressure of the gas after compression.

Let us now see what heat would be produced per hour by the working of the larger blowing engine, described on page 34, Vol. I. The pressure attained in the air conduit cannot be correctly ascertained from the depth of liquor blown through, although it may be approximately determined in this manner. In an actual experiment, 16 ft. depth of liquor produced a pressure (p) of 10 lbs. per square inch above the atmosphere in the air main, or 50 inches of mercury column above a vacuum. The temperature of the air was 15°C. , the atmospheric pressure 30 inches of mercury, while ρ , the specific heat ratio, may be taken as :—

$$\rho = \frac{C_p}{C_v} = 1.41$$

Our formula then becomes :—

$$t^\circ = \left\{ \left(\frac{50}{30} \right)^{1.41} \times 288 \right\} - 273 = 61^\circ \text{C.} \quad (b)$$

which is the temperature of the air throughout the process, and this amount shows an increase of temperature of 46°C. The engine takes in 100,800 cubic feet of air per hour, or 7,672 lbs., so that :—

$$7,672 \times 46 \times 0.238 = 83,993 \text{ C.H.U.}$$

per hour. In the manganese oxidation process this heat is beneficial rather than otherwise, so there is no need for any further cooling than that necessary to keep the india-rubber valves of the blowing engine cool, but if it were required to cool down the air to atmospheric temperature by means of a surface condenser, the quantity of water—entering at 10°C. and leaving at 40°C. —to be supplied, would be :—

$$\frac{83,993}{30 \times 10} = 280 \text{ gallons per hour.}$$

The temperature produced by the compression of any other gas may be readily calculated in a similar manner, inserting the values of $\left(\frac{p}{P} \right)^{\frac{\rho-1}{\rho}}$ for each particular gas and pressure produced, and adding, if need be, the value

of the latent heat of evaporation when the gas is compressed to the liquid state.

Let us now suppose carbon dioxide at 10°C. to be compressed to 20 atmospheres above a vacuum. Here

$$\left(\frac{p}{P}\right)^{\frac{\rho-1}{\rho}} = \left(\frac{20}{1}\right)^{\frac{31}{131}} = 2.0316$$

so that

$$t^{\circ} = (2.0316 \times 283) - 273 = 302^{\circ}\text{C.}$$

and the cooling water required to carry off this heat may be ascertained in the same manner as already described for air.

Gas compressors are usually rated as being able to compress a certain volume to a given pressure, and the exact meaning of this should not be mistaken. Thus, a compressor rated at 670 cubic feet per minute, at 100 lbs. per square inch, should compress 670 cubic feet of air at the atmospheric pressure (generally called "free air") to the higher pressure of 100 lbs. per square inch, which would be equivalent to 7.8 atmospheres absolute. In stating the capacity of a compressor, it is usual to take the cubic contents of the cylinder calculated from its diameter, and the length of the stroke of the piston, but this, of course, is an outside figure, and though it sometimes gives results near enough for practice, it must be remembered that the actual volume is somewhat less than this, owing to leakages past the piston and valves, and the loss by clearance space, of which more will be said later. In good compressors, these losses vary from 5 to 10 per cent., but with compressors of inferior construction, the loss may be very much more.

The theoretical power needed to compress a gas from atmospheric pressure to any pressure above this, may be readily calculated; but the power actually required in practice will depend upon the construction of the compressor, and the excellence of all its working parts. Compression may take place in two distinct ways; in the first, the gas neither receives nor rejects heat during the process—this is termed *adiabatic compression*, while the process of compression in which the temperature of the gas is kept constant is called *isothermal compression*. The compression would take place *adiabatically* were the cylinder a perfect non-conductor of heat, which we know is not the case, and in practice the compression line is generally found midway between the *adiabatic* and *isothermal* curves. *Isothermal compression* takes place whenever the heat of compression is conducted away as fast as it is generated, but in the actual working of a gas compressor, time could scarcely be allowed for the operation to take place *isothermally*. *Stage compression* with *intercooling*, which will be referred to later on, enables us to approach the *isothermal* line more closely than when the heat is allowed to escape without assistance.

The following diagram has been prepared to show the effect of both *isothermal* and *adiabatic* compression of air from the ordinary atmospheric pressure to 150 lbs. on the square inch, by the aid of which many of the problems presented in practice may be solved without recourse to the more complicated algebraical formulæ.

The theoretical power required to compress air isothermally may be found from the expression :—

$$p V \log_e r = \text{foot pounds}, \quad (c)$$

where p is the initial pressure of the gas in pounds per square foot absolute, and V its volume in cubic feet, r being the ratio of compression.

If we desire to know the power required theoretically for adiabatic compression, it is :—

$$P_1 V_1 - P_2 V_2 + \frac{P_1 V_1 - P_2 V_2}{\gamma - 1} = \text{foot pounds} \quad (d)$$

P being reckoned in pounds per square foot, the first term representing the final pressure and volume, while the second term represents the initial

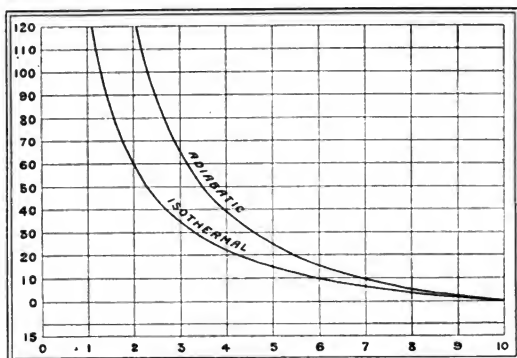


FIG. 107.—ADIABATIC AND ISOTHERMAL COMPRESSION LINES.

pressure and volume. From these two formulæ the diagram Fig. 108 has been constructed, which will be found to simplify all such calculations for use in practice.

The diagram shows the number of foot pounds theoretically required to compress one cubic foot of air to various absolute pressures, that is, reckoned above a vacuum — 14·7 pounds per square inch being the equivalent of one atmosphere, representing air under ordinary conditions.

In practice, however, it is rare that compression takes place either fully adiabatically or isothermally, so that it would be well to take the mean of these figures, and also to make considerable allowance for other losses of energy, the existence of which may best be illustrated by taking an example from the sulphuric acid industry.

The "blowing engine" attached to the acid eggs of a nitre recovery plant has to supply air for the purpose of raising acid to the cisterns upon

the tower tops, at a pressure of 50 lbs., more or less, above the atmosphere, or an absolute pressure of 64·7 lbs. per square inch. At starting, the acid egg holds 35 cubic feet of sulphuric acid, which weighs approximately 100 lbs. per cubic foot. This acid requires to be lifted to a height of 60 feet. At the end of the operation, at the moment when the last drop of acid has been forced into the lower end of the delivery pipe, 35 cubic feet of acid have been driven into the acid cisterns, and its place is occupied in the egg by 35 cubic feet of air at a pressure of 64·7 lbs. absolute. In a few seconds more, the whole of this compressed air has escaped, and with it the power expended in producing it. Let us examine the position more minutely. Suppose the air-cylinder to be properly water-jacketed, and the cast-iron egg into which the air is compressed to be cold (10° C.). As the volume of compressed air will only weigh about 11·7 lbs., while the weight of the acid egg

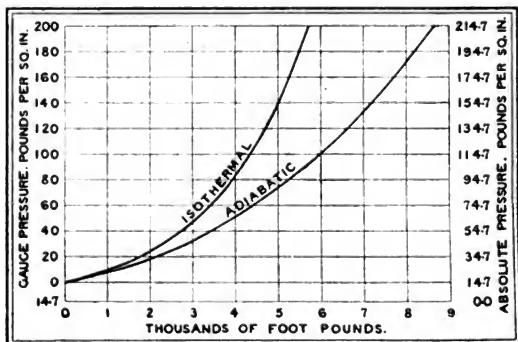


FIG. 108.—DIAGRAM OF POWER REQUIRED FOR AIR COMPRESSION.

is 6,237 lbs., it will be seen that there is every opportunity afforded for the escape of heat of compression. Starting with the air at 10° C., the 11·7 lbs. will be raised to :—

$$\left\{ \left(\frac{P}{P} \right)^{\frac{\gamma-1}{\gamma}} \times (273 + 10) \right\} - 273 = 161^{\circ} \text{C.}$$

so that the 11·7 lbs. would furnish :—

$$151 \times 11.7 \times 0.238 = 420 \text{ C.H. units}$$

reckoned at the specific heat of air under constant pressure. This would heat up the 6,237 lbs. of cast-iron about one-half of one degree Centigrade. We may, therefore, presume that the acid egg contains air that has been practically compressed isothermally, but the assumption is not theoretically correct, as, though we end the process with the 35 cubic feet required

by isothermal compression, the work expended is considerably in excess of that required by strictly isothermal requirements.

Reference to the diagram Fig. 108 will show us that one cubic foot of free air compressed isothermally to 50 lbs. per square inch gauge pressure will require theoretically 3,050 foot pounds; therefore, the minimum number of foot pounds required to compress 154 cubic feet of free air would be :—

$$154 \times 3,050 = 470,000 \text{ foot pounds.}$$

The energy required for adiabatic compression is also seen from the diagram to be 4,000 foot pounds, or a total of :—

$$154 \times 4,000 = 616,000 \text{ foot pounds.}$$

In this case, the actual energy required lies somewhere between these two extremes. To place this graphically before the student, the following diagram has been constructed :—

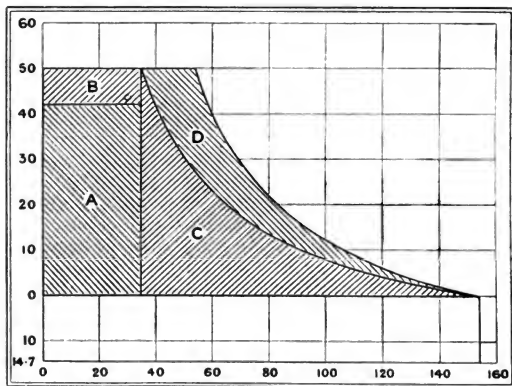


FIG. 109.—DIAGRAM OF THE THEORETICAL PERFORMANCE OF AN O.V. AIR COMPRESSOR.

The combined figures A, B, C, D in the diagram represent the total work done in compressing 154 cubic feet of free air adiabatically to a volume of 54 cubic feet, which is subsequently cooled under constant pressure, so that it finally occupies a volume of 35 cubic feet, and in raising 3,500 lbs. of acid to a height of 60 feet. Were there no heat lost in the operation, the air would have been heated to 161°C ., but as already shown, the heat of compression is dissipated almost as quickly as it is generated, and the gauge shows a constant pressure of 50 lbs. per square inch. These numbers may be readily followed on the diagram, where the horizontal figures indicate the volume in cubic feet, while the vertical figures show gauge pressures above the atmosphere.

The areas represented by the letters A, B, C show the work required, had the compression taken place isothermally, but in actual practice the compression line occupies a position somewhere between the isothermal and the adiabatic curves, as may also be seen in Fig. 112. The irregular area D indicates the loss of energy due to the generation of heat, while the rectangles A and B show the work absorbed in raising the acid; the combined areas C and D representing the work done on the air which finally escapes from the egg and is lost. The rectangle A indicates the number of foot pounds required to raise the acid, presupposing the absence of all resistance to motion, so that the rectangle B will show the work lost in friction between the acid egg and the receiving cistern.

Working out the figures from the formulæ already given, we find :—

Total work performed adiabatically	616,000	foot pounds
Dissipated in heat, etc.	146,000	" "
Work done on acid	252,000	" "
Lost in escaping air	218,000	" "

Let us now compare these figures with those obtained from the steam end of the compressor. The steam cylinder was eight inches in diameter, with a stroke of 18 inches, the steam being cut off at three-fifths. By the application of formula *c*, on page 309, Vol. I., we shall find that such an engine running at 60 revolutions per minute, and with a mean effective pressure of 25 lbs. in the cylinder, will develop 1,350,000 foot pounds during the six minutes occupied in the operation of raising an egg of acid, and as the total work expended on the air and acid amounted to 616,000 foot pounds the efficiency of the steam end of the compressor was 45 per cent. The work done in raising the acid being 252,000 foot pounds, the efficiency of the compressor as an acid raiser was 19 per cent. We also learn from these figures that the practical efficiency of the air cylinder was but 72 per cent. of its cubical contents, and that the H.P. required to compress one cubic foot of free air to 50 lbs. gauge pressure was 0.26. Actual figures may always be obtained by "indicating" the air cylinder and the steam cylinder of a compressor during a working operation, and the results will sometimes be found astonishing.

So much for the efficiency of an air compressor, and that this is not an abnormal case may be gathered from the following table, which has been partly constructed from material gathered from a paper on raising water by compressed air, by Mr. W. H. Maxwell,* and partly from the catalogues of compressor builders.

The calculation for theoretical work has been based on isothermal compression, which should be the aim of every maker of these machines, and from this table the reader will be able to properly appraise the value of those claims to efficiency exceeding 90%, which one sometimes meets with. These results are intimately connected with the compressor diagrams that have been already given, and, of course, the best way of ascertaining the true value of a compressor taken as a whole is to secure a diagram both from

* British Association of Waterworks Engineers.

the air cylinder and the steam cylinder when working normally. The figure of either may be faulty, but it would be wrong to blame one portion of the machine for the shortcomings of the other.

TABLE 19.

SHOWING THE EFFICIENCY OF AIR COMPRESSORS.

	Air pressure pounds per sq. inch.	H.P. per cu. ft. free air.	Theoretical H.P. Isothermal.	Efficiency.
Solvay Works, Saaralben	176	0·434	0·164	0·37
Brostowe Estate, Friedheim	140	0·376	0·151	0·40
Tunbridge Wells Waterworks	100	0·201	0·131	0·65
Do. do. do.	80	0·189	0·119	0·63
Do. do. do.	60	0·159	0·103	0·65
Sugar Refinery, Glogau	45	0·145	0·088	0·61
Yard Works, Zwickau	30	0·121	0·069	0·57
Ingersoll Sergeant Co.	100	0·199	0·131	0·66
Do. do.	60	0·147	0·103	0·70
Do. do.	30	0·094	0·069	0·73
Do. do.	20	0·069	0·052	0·75
Tilghman's Sand-blast Co.	100	0·200	0·131	0·65
Example on page 225	50	0·261	0·094	0·36
W. Neill and Sons, St. Helens	80	0·206	0·119	0·58

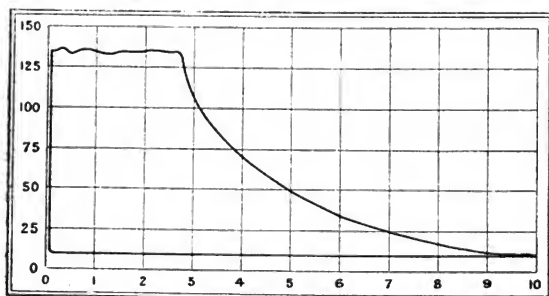


FIG. 110.—DIAGRAM FROM AMMONIA COMPRESSOR.

The diagrams already given are, as stated before, entirely theoretical, and but little practical information can be obtained by their use alone, but if we take the figure obtained in an actual trial, such as that shown in Figs. 110 and 111, we shall learn much from them. The former (Fig. 110) is the diagram from a single acting ammonia compressor making 40 revolutions per minute, and the square heel testifies to the small amount of power and

volume lost by clearance space. From this diagram the weight of ammonia gas taken in and compressed may be readily calculated, and a diagram taken simultaneously from the steam cylinder will show the volume and pressure of the steam employed to produce the compression. The numbers so obtained will not be found to agree with those obtained by the application of formula *c* and *d*, page 223, which are entirely theoretical.

Clearance, generally styled by Continental engineers "noxious space," seriously affects the capacity of any compressor, as it leaves a cushion of compressed gas at the end of the stroke, which prevents the opening of the suction valves, until the pressure has been sufficiently reduced by expansion. The evils of "clearance" increase with the pressure to which the gas is subjected, but there are methods whereby these difficulties may be nullified in practice, as we shall see later on.

A diagram showing the effect of compression in a cylinder with clearance spaces is to be found in Fig. 111. The round heel of the figure demonstrates.

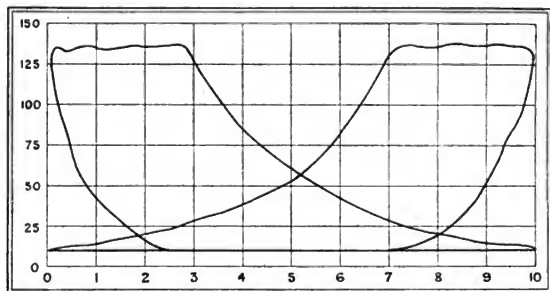


FIG. 111.—DIAGRAM FROM BOTH ENDS OF AN AMMONIA COMPRESSING CYLINDER.

the loss of volume taking place at each stroke of the compressor, showing clearly the reason why the measurement of the capacity of a cylinder by multiplying the stroke into the area produces an extreme figure. There may be other reasons for the existence of this "round heel," but for the moment we may ignore them.

The actual conditions existing in practice may be seen on reference to the two following diagrams taken from the steam and air cylinders of an ordinary vitriol plant air compressor, made by Messrs. W. Neill and Sons, of St. Helens, for one of the author's clients.

The particulars of this compressor were as follow:—Steam cylinder, diameter 10 inches, stroke 18 inches, normal number of revolutions per minute 48. Air cylinder, diameter nine inches, stroke 18 inches, for a maximum working pressure of 80 lbs. per square inch. During the trial at which the diagrams were taken, the boiler pressure was 55 lbs. per square inch, taken in the steam main close to the engine, and the number of revolu-

tions 48, the speed being regulated by partly closing the steam valve at the entrance to the cylinder. The air-cylinder was connected with an air-chest, loaded to maintain a constant pressure of 80 lbs. per square inch.

An examination of the diagram from the air cylinder is instructive. It is a fairly good figure for a compressor of this kind, perhaps above the average, but it shows that one end of the cylinder was working slightly better than the other during the trial. For comparison with the theoretical work of the compressor, the adiabatic and isothermal lines have been shown, dotted in. From this diagram we learn that the mean effective pressure acting against the piston was 32.08 lbs. per square inch, which represents 8.76 H.P.

Turning now to the diagram from the steam cylinder (Fig. 113) we see at once that it differs considerably in detail from the diagram shown by

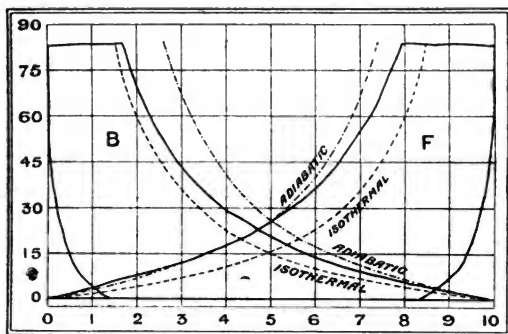


FIG. 112.—DIAGRAM FROM AIR CYLINDER OF VIEILLE AIR-COMPRESSOR.

Fig. 155, on page 352, Vol. I. It differs chiefly in the direction that the mean pressure in the cylinder is obtained by throttling the steam valve at the entrance to the cylinder, admitting only just sufficient steam to keep the compressor running at the normal number of revolutions, which in this instance was 48. It will also be seen that the steam follows the piston to the point C where the cut-off is made, while the point of release is shown by the letter R. From the point R we are able to calculate approximately the volume of steam entering the cylinder at each stroke. The form of the steam line is not important in engines of this description where the pressure is regulated by the process of throttling the inlet to the cylinder, but it serves the useful purpose of enabling the mean effective pressure to be calculated, and from it the horse-power actually employed. In the trial now under consideration, the mean effective pressure works out to 36.08, and the horse-power to 12.38. The weight of steam per horse-power hour is also shown

to be 32.5 lbs., or 402 lbs. per hour. The percentage of work lost amounts to 29.2, which includes the friction of the engine and air cylinder, so that the percentage of work done on the air in relation to steam is 70.8 per cent. Referring again to the steam actually used as 402 lbs. per hour, it must be pointed out that this is only the minimum vapour expelled from the cylinder. There are several sources of loss that will bring up this figure considerably, in this case probably by over 10 per cent., so that the feed-water corresponding to the foregoing amount of steam would probably be 442 lbs. per hour. At 7 lbs. of water evaporated per pound of coal, this would mean 44 cubic feet of free air compressed to 80 lbs. per square inch by the combustion of one pound of coal, on the assumption that the effective air-cylinder capacity reached 90 per cent.

There are not many results of trials of stage compressors available for public use, but the following results of the trial of a two stage installation

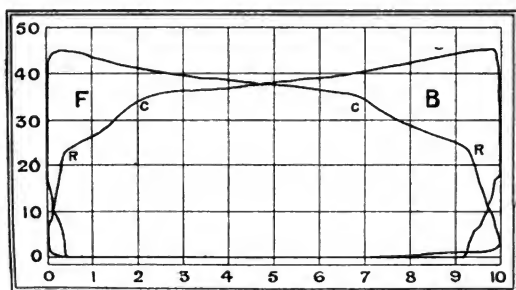


FIG. 113.—DIAGRAM FROM STEAM CYLINDER OF VITRIOL AIR-COMPRESSOR.

have been published by Messrs. Alley and Maclellan, Ltd., of Polmadie, near Glasgow, as illustrating the work of one of their machines. The compressor was belt-driven, working against a receiver pressure of 100 lbs. per square inch, with a guaranteed output of 300 cubic feet of free air per minute.

Barometer, 30.2 inches. Shop temperature, 54° F. Receiver temperature, 102° F. Volume of receiver and pipes, 52.67 cubic feet. Speed of machine, 230 R.P.M. At working load governor variation, 2½ lbs.

Air pressure in receiver

	80	100	120
M. S.	M. S.	M. S.	M. S.
Time taken to fill receiver from atmosphere	0-51½	1-4½	1-17½
Revs. taken to fill receiver from counter	198	247	296
Volume swept by piston	291.4	363.5	435.7
I.H.P. of L.P. air cylinder (mean of 3)	18.6	21.4	21.5
I.H.P. of H.P. air cylinder (mean of 3)	21.2	25.1	30.9
Total mean I.H.P. of air cylinders	39.8	46.5	52.4

- A. At working load the machine pumped reservoir, having 52.67 cubic feet capacity to 100 lbs. at 102° F. in 246 revs. in 1 min. $4\frac{1}{2}$ sec., barometer being 30 ins. and atmosphere 54° F.

$$\text{Air compressed} = 52.67 \times \left(\frac{114.75}{14.75} - 1 \right) \times \frac{460^\circ + 54^\circ}{460^\circ + 102^\circ} = 327.3 \text{ cubic feet}$$

of free air at 54° F., or 305 cubic feet per minute.

No credit is taken for leakage from pipe system.

- B. Volume swept by piston = $1.767 \times \frac{10}{12} = 1.472$ cubic feet per revolution

$$\text{,, ,,} = 1.472 \times 230 = 338.5 \text{ ,, minute}$$

$$\text{Volumetric efficiency} = 100 \times \frac{305}{338.5} = 90.2\%.$$

- C. Machine shows compressing 305 cubic feet per minute to 100 lbs. 46.5 I.H.P.
 Isothermal compression of same quantity requires 40.0 "
 Adiabatic " " " 55.4 "

Mention has already been made of the use of compressed air for use in motors; it is also employed in glass-blowing on the large scale, for rock-drills, pumping, and many other applications. For such purposes as the foregoing care must be taken to thoroughly cool the gases before entry into the compressed air main, otherwise there will be serious losses between the compressing station and the place where the compressed air is to be utilised. Further, the compressed air in expanding will absorb heat, and in so doing produce disturbances which, if not duly recognised at the outset, may prove serious. It is a common practice to reheat the air just before expansion, putting in the exact amount which would be withdrawn during the dilatation. The re-heating of compressed air for motor purposes has been investigated by several experimenters. Mr. W. G. Walker, at the Bradford meeting of the British Association in 1900, gave an interesting account of some experiments made by Prof. Nicolson, from which the following particulars have been taken:—The air was used in an ordinary steam engine of the Corliss type, of about 27 indicated horse-power. When employed without re-heating 850 cubic feet of free air were used per indicated horse-power per hour. The air was then heated to 142° C., by passing the compressed air through pipes heated by coke, under which condition 640 cubic feet of free air was used per indicated horse-power per hour, being a reduction of 210 cubic feet of free air per indicated horse-power per hour, due to re-heating. Thus a saving of 25 per cent. is effected in the quantity of air used. This saving was effected by the burning of 348 lb. of coke per horse-power hour. The results may be stated as follows:—100 horse-power in cold compressed air was raised to 133 horse-power when re-heated to a temperature of 142° C., by an expenditure of 47 lbs. of coke per hour, or at the rate of 1.42 lbs. of coke per horse-power per hour additional. This is equivalent to an additional horse-power for every pound of coal burnt in the heater, which is far more economical than the most efficient steam engine and boiler.

Prof. Riedler tried an old 80 H.P. steam engine in Paris, which had been adapted to work as an air motor, and which was actually yielding 72 I.H.P. with compressed air at 80 lbs. pressure. He found it to be using 430 cubic feet of free air per H.P. when this was heated to 150° C. This re-heating only required the expenditure of 15 lbs. of coke per hour.

In dealing with compressed air, it is necessary to consider its flow through pipes. Compressed air follows the ordinary laws for elastic fluids, such as air, steam, etc., which have been already dealt with in Vol. I. The works of Rankine, Peclet, and others may be referred to, for the higher mathematics of this subject, it being quite sufficient in a practical work such as this to give a simple formula that will readily allow the flow of compressed air to be deduced. Such a formula is :—

$$C = 13 P \sqrt{\frac{D^5 (P - p)}{l d}} = \text{cu. ft. free air per minute.} \quad (e)$$

Where C = cubic feet of free air per minute

D = diameter of the pipe in inches

d = density of the compressed gas when air at ordinary atmospheric pressure = 1.0.

l = length of the pipe in feet

P = initial gauge pressure in pounds absolute per sq. in.

p = terminal pressure in pounds absolute per sq. in.

The figures yielded by the foregoing formula, though approximate only—and it would need a very complicated formula to be rigidly exact—are quite good enough for practical work; let us take an example from the catalogue of a large firm of compressor builders, who state therein that a pipe 10,000 feet long and three inches diameter will deliver 1,961 cubic feet of free air per minute, when the initial pressure is 1,100 lbs. per square inch, and the terminal pressure 1,050 lbs. The formula gives :—

$$C = 13 P \sqrt{\frac{D^5 (P - p)}{l d}} = 13 \times 1,115 \sqrt{\frac{243 (50)}{10,000 \times 74}} = 1850$$

which is quite near enough, when all the uncertainties of an installation are taken into account. We shall find from this formula that a pipe one-inch in diameter is ample to convey the compressed air from the compressor of a vitriol plant to the acid egg when the distance is less than one hundred feet, and the pressure above 60 lbs. per square inch, but in practice it is usual to make the diameter 1½ inches.

A few words may now be said upon the construction of compressors, but, as this is a large subject, and full of complex detail, only a few points will be dealt with, so as to put before the reader some of the conditions of working with which he should be familiar. If we refer to the diagram taken from a steam cylinder, and compare it with a card taken from the air cylinder of a compressing pump, we shall find that in what are called straight-line compressors, the higher pressures come upon the pistons at extreme positions during the stroke, that is to say, the steam pressure is greatest at the commencement of the stroke, while the air pressure is greatest at the end of it.

In fact, as will be seen by reference to the diagram on page 352, Vol. I., the pressure exerted by the "toe" of the diagram will have but little effect in overcoming the resistance offered by the compressed air. In practice, the work is equalised in two ways; in one, the steam is admitted into the cylinder during the whole length of the stroke, as in the Westinghouse compressor, while in the other a heavy fly-wheel is made to take up the momentum of the early part of the stroke, and transfer it to the piston during the later portion of its travel. In compressors of the latter type, the engine must run quickly if it is to receive the full benefit of the fly-wheel. A careful study of crank effort should also be made in connection with the subject of air compression.

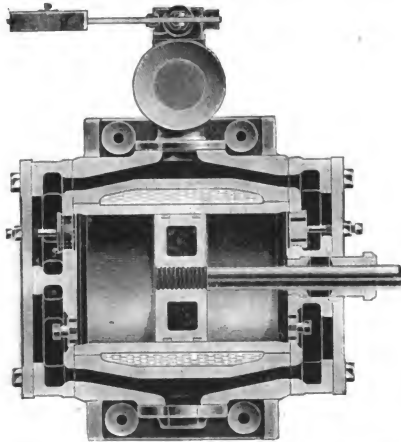


FIG. 114.—SECTION THROUGH CYLINDER OF AIR COMPRESSOR.
(Tilghman's Patent Sand-Blast Co.)

The valve system of a compressor is also a point to which considerable attention should be directed by those in charge of this class of machinery. When the valves are too heavy, especially upon the suction side, the piston is often well on its journey before the valves will open normally, and even when the charge is finished the exit valves may not let it escape readily enough. What is a more common fault with cheap machines is that the clearance space does not allow of the full volume being discharged, though the whole of the work has been done upon it. It is quite a common fault with many air compressors that the suction valves do not close early enough, so that a portion of the charge is lost thereby, a fact that can be readily demonstrated by the use of a lighted taper. In a cheap design once examined by the author, the air delivered under a pressure of 40 lbs. per square inch

did not exceed 40 per cent. of the available capacity of the air cylinder. Some air compressors are built with slide valves, a form of construction which is allowable in all cases where the construction and installation are both carried out with intelligence.

We may now pass to the examination of a few valves of approved pattern, taking the first example from the compressors made by the Tilghman's Patent Sand-blast Co., of Broadheath, the volumetric efficiency of the cylinders being over 90 per cent.

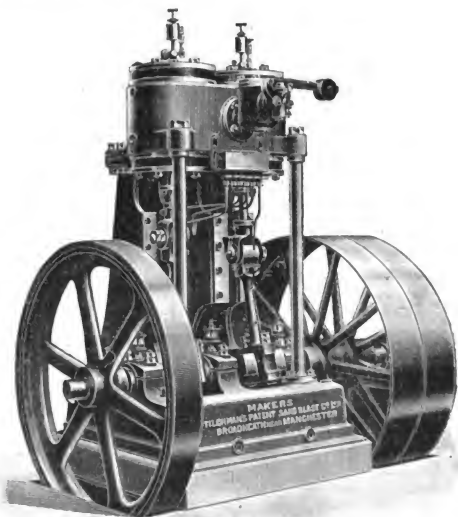


FIG. 115.—TWO-STAGE AIR COMPRESSOR.
(Tilghman's Patent Sand-blast Co.)

The ends of the cylinder in these compressors are not water-cooled, but are utilised as valve chests, and in this manner the clearance space is reduced to a minimum. The valves themselves are extremely light, and both open and close with the slightest difference in pressure between the two sides. The general style of these compressors is shown by Fig. 115, which, however, depicts a form in which the compression is effected in two stages, with an inter-cooler between the two cylinders. The form and character of the valves, however, is the chief feature. These compressors are also fitted with an automatic inlet valve. When the working pressure is

exceeded the inlet is automatically closed, putting the piston into equilibrium by causing a partial vacuum on both sides of it, which allows the engine to run without resistance.

Fig. 116 shows a section of the air-cylinder of an Ingersoll-Sergeant compressor, with its system of valves and water-jacket. The valves are large in area and light, and cannot be drawn into the cylinder. The cylinders are completely water-jacketted, not only round the barrels but through the heads as well, as the removal of the valves to the side allows of the heads being cooled completely. The makers assert that the cooling heads are much more effective than the cylinder jackets, as the temperatures are highest near the end of the stroke where the highest pressures occur.

Another form of valve arrangement adopted by the Ingersoll-Sergeant Co. is the piston inlet valve shown in Fig. 117. The two inlet valves are

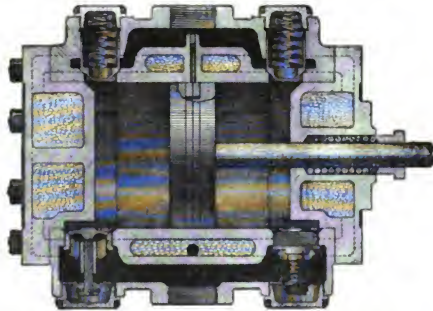


FIG. 116.—INGERSOLL-SERGEANT AIR COMPRESSOR CYLINDER.

placed in the piston as shown at G and G, and with the tube E are carried backward and forwards with the piston. The valve on that face of the piston which is toward the direction of motion is closed, while that on the opposite face is open. This is exactly as it should be in order to discharge the compressed air from one end of the cylinder while taking in the free air at the other, and when the piston has reached the end of its travel there is of course a momentary stop while the engine is passing over the centre, and an immediate start in the other direction. The valve that was open now immediately closes, and as there are no springs used there is no chattering or hammering so frequently heard with poppet valves. In the Figure (117) A is the water inlet, B the outlet, E the air inlet, F the air discharge, while H are the discharge valves and J the water jacket.

Before proceeding further we may enquire, what is the object sought in compression? when we shall find the answer in four distinct directions. Compression may be required for:

- a. Moving large volumes of air against a light pressure, such as exists in the manganese recovery process.
- b. Producing smaller volumes at higher pressures, as for short air-lifts, elevating acids and general monte-jus work.
- c. Producing high pressure air for motors, rock-drills, high air-lifts etc.; and
- d. Liquefying gases.

In the first class we must place the well-known Weldon blowing-engine, as it serves as an example of a low pressure compressor, producing as it does a large volume of air at from 8 lbs. to 10 lbs. per square inch. The Figure on page 237 shows a pair of engines of this type, constructed by Messrs. R. Daglish and Co. of St. Helens, for oxidising the manganese

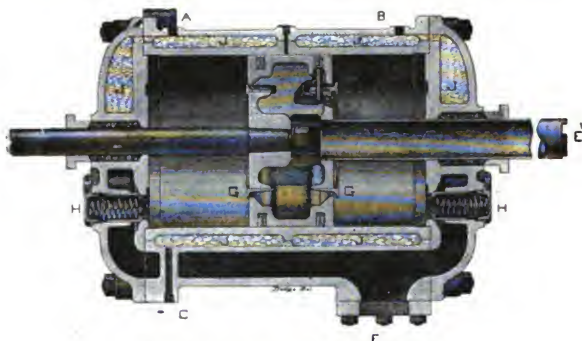


FIG. 117.—INGERSOLL-SERGEANT COMPRESSOR.
(Piston Inlet Valves.)

mud for 200 tons of bleaching powder per week at the Osaka Chemical Works in Japan. The two steam cylinders are each 26 inches in diameter, and the air cylinders 36 ins. diameter, all working to a common stroke of four feet. They are fitted with a horizontal air-pump and condenser, and the steam cylinders are supplied with a variable expansion gear. A blowing-engine of the description illustrated would cost approximately £1,600, more or less according to the state of the markets for the time being. Reference to the performance of a compressor of this type has already been made in Table 113, on page 453 of the first volume.

The second class of compressor comprises those used for raising acid and other liquids, the most general pattern of which is shown in Fig. 119. For chemical works use, these engines are usually made rough and strong so as to be capable of withstanding severe usage, which they generally get. It is usual to stow them away in some dark corner under the vitriol

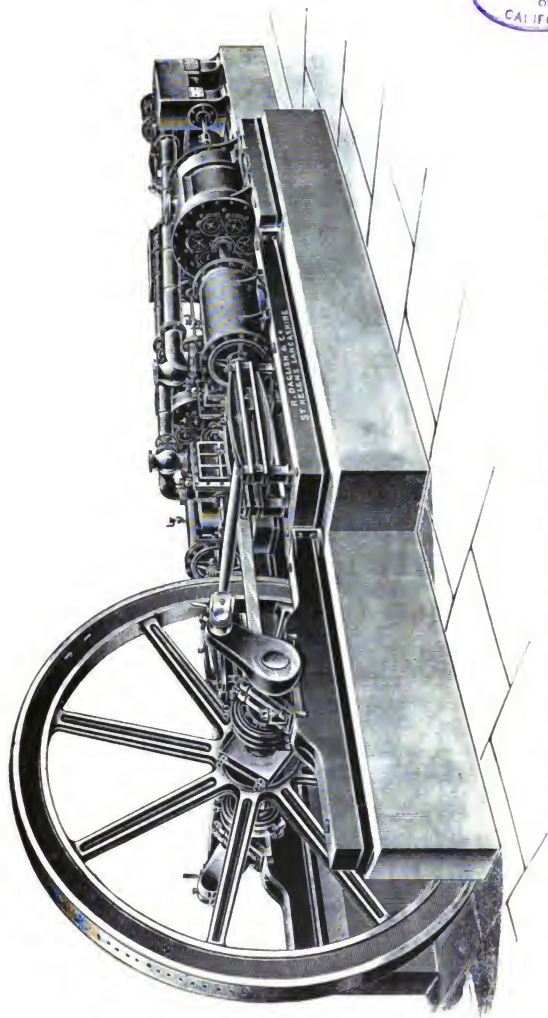


FIG. 118.—THE OSAKA WELDON BLOWING ENGINE (Messrs. R. Daglish and Co., St. Helens).

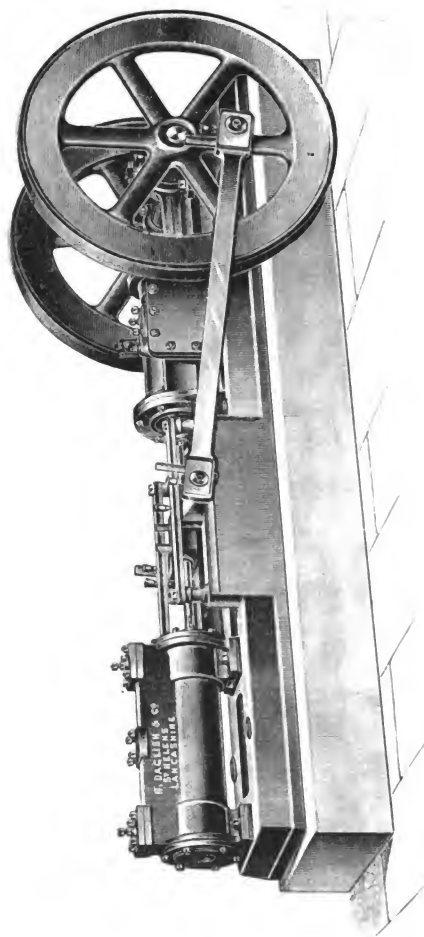


FIG. 119.—AIR COMPRESSOR (By Messrs. R. Darglish and Co.).

chambers where any defects that may be developed during use may not be so readily seen. The cost of a compressor of this type (Fig. 119), exclusive of foundations, is approximately £100, and the size, with 6 inch air cylinder, 8 inch steam cylinder, and 18 inch stroke will amply serve a set of absorbing and denitrating towers working under ordinary conditions. Messrs. W. Neill and Son, of St. Helens, are also makers of a compressor similar to that shown by Fig. 119, and Fig. 120 is also an illustration of a twin-cylinder compressor built by the same firm for supplying air for motor purposes at pressures up to and beyond 100 pounds per square inch. This form of construction, called by some makers "duplex," allows the pressure on the crank shaft to be better equalised than is the case with single cylinders, and such engines run very steadily as a rule.

We now come to section *c* of our classification, which consists of the compressors employed in mining work, motors generally, air-lift water

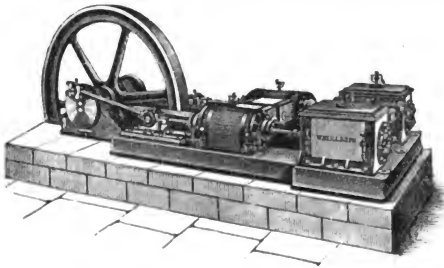


FIG. 120.—TWIN-CYLINDER COMPRESSOR.
(Messrs. W. Neill and Son.)

raisers, and such like purposes. These are now being built for very high pressures, but beyond mention of the fact that the Metropolitan Street Railway of New York City employs air for motor purposes at 2,500 per square inch, little more may be said, as the ordinary pressures at which air is applied for such purposes as already described will not probably exceed 150 pounds per square inch on an average. There are many patterns that will economically produce air at this pressure. Even the simple compressor shown by Fig. 119 may be used up to one hundred pounds, but when large volumes of air compressed so highly are demanded, it is well to be careful in the selection.

Some of the evils of unskilful work, either in the design or in the fitter's province, have already been pointed out, but perhaps sufficient stress has not been laid upon them. These evils may not be so readily recognised when low pressures are concerned, but they cannot be neglected under a resistance of seven atmospheres. When compressing to 100 lbs. per square inch in a single cylinder, the unexpelled air in the clearance

space, whenever such exists, must expand nearly eight times before the inlet valves can open, so that in the case of a compressor with 6 per cent. of clearance the volumetric efficiency will be reduced to below 55 per cent., or, in other words, the compressor must either possess a larger cylinder or run more quickly than one of similar size, but which has been well designed. In a compressor once examined by the author, the clearance space at each end of the cylinder amounted to three-eighths of an inch, so that the loss of volume would amount to three inches per stroke at a pressure of eight atmospheres.

Professor Wellner, of Brunne, first pointed out the evil effects of clearance spaces in piston compressors, and by various means he endeavoured to overcome the difficulties, but was not successful, though he led the way for Messrs. Burckhardt and Weiss's improvements, and still later for the

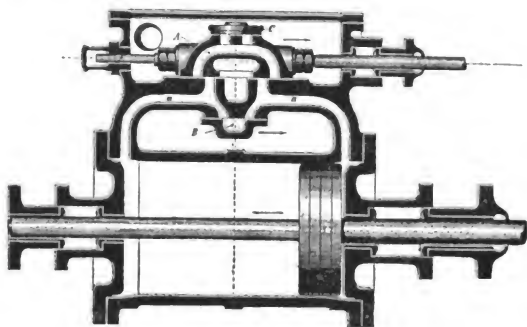


FIG. 121.—WEGELIN AND HÜBNER'S AIR PUMP.
(Section through cylinder.)

system of Messrs. Wegelin and Hübner, of Halle. The improvements of this last firm may be found illustrated in Fig. 121, which represents a section through the air-cylinder.

In this form of construction the air is admitted to the cylinder by means of a slide valve, and a second slide or equaliser is added, which allows the air in the clearance space already compressed in front of the piston, to find its way to the suction side, where it is drawn in with the entering air. When the piston recedes the air pressure is immediately lowered, so that it produces suction from the commencement of the stroke. Nowadays the clearance space allowed is practically *nil* in compressors of the best construction.

It is in this class of cylinder that the advantages of stage or compound compression are realised, as when gas is compressed, even to 100 pounds per square inch in a single cylinder, a temperature of 260° C. is

often reached. As this is nearly the temperature at which a gas doubles its volume from the ordinary temperature of the air, it will be readily seen that the cylinder will only contain or take in one-half the weight of air, which would enter were the cylinder cold. Compressors built especially for extreme resistances are nearly always constructed for compression in stages. The single cylinder pump, such as is employed in connection with refrigerating machines, may be used with advantage, say up to 100 pounds per square inch, and even beyond this in special cases, as it is less complicated and less costly than the stage compressors, but of course the cylinder must be free from "clearance" spaces.

By the courtesy of Messrs. George Scott and Son, of Christian Street, London, the author is able to give an illustration of a compressor designed for the Royal Institution. It may be as well to add that Professor Dewar had much to say as to the design, that it has been used in the production of liquid oxygen and liquid hydrogen, and that it is also in use for liquefying carbonic acid gas and the compression of other gases at high pressures.

The compressing cylinders are 11 ins., 6 ins., and 2 ins. diameter, with a common stroke of 9 ins., but, as the machine was designed for working at 100 atmospheres (1,500 lbs. per square inch) with 30 lbs. steam boiler pressure, the steam cylinder is much larger than would be necessary in most installations. The compressor is made with its three cylinders arranged so that the low pressure and high pressure pistons are moving in one direction, while the intermediate piston is moving in the reverse direction, so that at 100 atm. terminal pressure, the working loads on the combined low and high pressure pistons balance the load on the intermediate piston. The compressor illustrated by Fig. 122 will take in 44 cubic feet of gas per minute when running at 90 revolutions.

Let us now consider the working of one of these machines as compared with a single cylinder having its piston of the same diameter as the largest of the stage compressor, the single cylinder being externally cooled, and the compound machine possessing externally cooled cylinders, with cooling coils between each.

If we take the area of the single cylinder as 95 square inches and multiply it by 425 lbs. (which is the approximate mean pressure for 100 atmospheres), we get a piston load of 40,375 lbs. In the stage compressor the mean load on 95 ins. is 35 lbs., and on 3 ins. it is 980 lbs., giving respectively piston loads of 3,325 and 2,940 lbs., which together equal 6,265 lbs. moving in one direction; and 28 ins. (the area of the intermediate piston) multiplied by 219 lbs. (the mean pressure on that piston) is equal to 6,132 lbs. moving in the opposite direction. This it will be seen is nearly the same as the combined pressures of the high and low pressure cylinders moving in the reverse direction, and added together as the total load to be moved, is 12,397 lbs., as against 40,375 lbs. of the single cylinder—a very considerable economy, which is also further increased by the better cooling power of the coils. Where the compressors are used for gases other than air, provision is made for returning any slight leakage past the pistons to the suction.

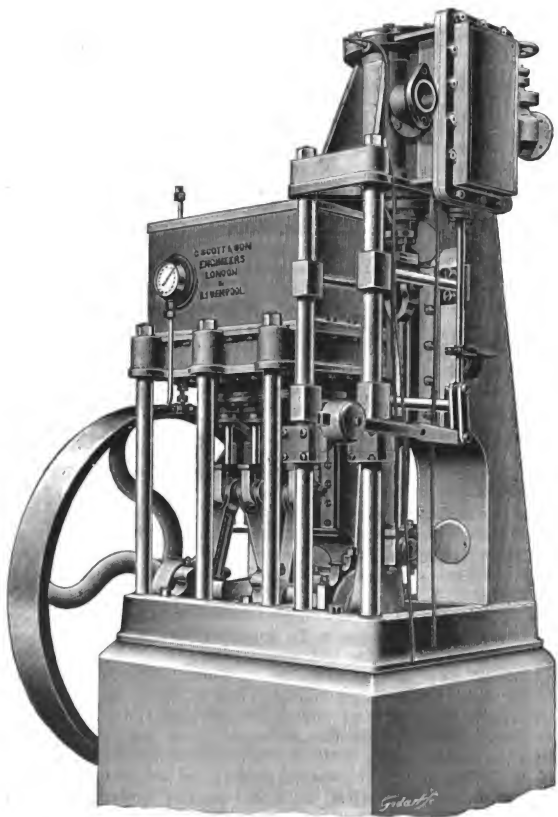


FIG. 122.—STAGE COMPRESSOR FOR GASES.
(Built for the Royal Institution by Messrs. George Scott and Son, of London.)

The compressed-gas industry has now assumed very fair dimensions. Compressed carbonic acid gas is now met with regularly in commerce, and sulphurous acid, chlorine, hydrogen, oxygen, nitrous oxide, and even liquid air are just as readily obtainable. Some of these, as hydrogen and oxygen, are compressed gases merely, while others take the commercial form as liquids, of which sulphur dioxide, ammonia, and chlorine are examples. In connection with this subject, the following table will be found useful, giving, as it does, the vapour tensions of some of the liquefied gases now met with in commerce, at various workable temperatures.

TABLE 20.

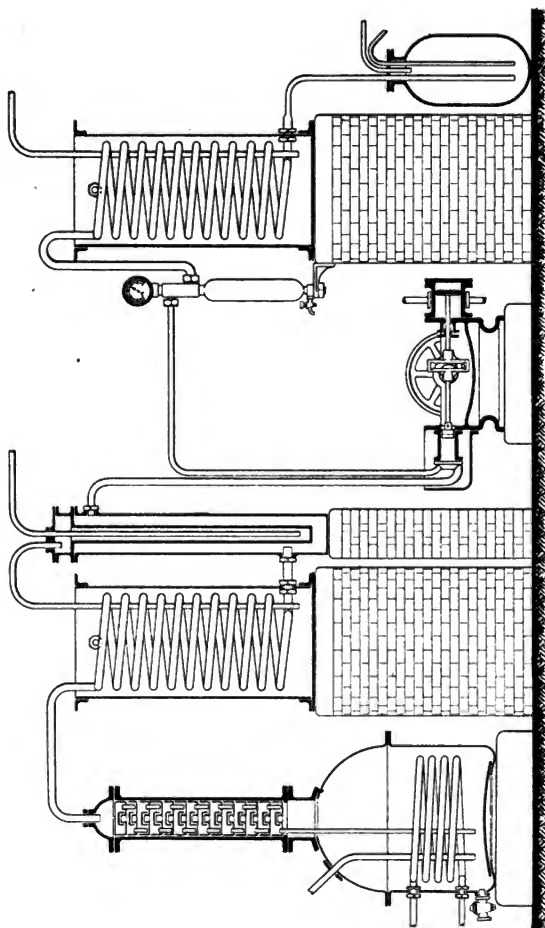
SHOWING THE VAPOUR TENSIONS OF SOME CONDENSED GASES

(In Millimetres of Mercury).

$\rho = \frac{C_p}{C_v}$	1'256	1'317	1'311	1'32	
°C.	SO ₂	NH ₃	CO ₂	Cl ₂	F.
—25	374	1100	13000	1140	—13
—20	480	1400	15150	1398	—4
—15	608	1740	17600	1694	5
—10	763	2150	20350	1998	14
—5	947	2620	23450	2386	23
0	1165	3180	27000	2781	32
5	1420	3830	30700	3230	41
10	1800	4570	35000	3762	50
15	2065	5420	39650	4370	59
20	2460	6390	44700	5031	68
25	2920	7480	50200	5798	77

In generating gases for compression, great attention must be paid to their purity and dryness, so that the methods employed for their production should have these objects well in view. Sulphurous acid and chlorine may be almost completely dried, on the large scale, by contact with strong sulphuric acid in the usual tower packed with clay rings, but of course ammonia cannot be dealt with in this manner. Ammonia may be dried over quicklime, but it is only occasionally dried in this manner before compression, as when the uncompressed gas is cooled to 10° C., the moisture it holds is practically of no moment.

If we refer once more to the diagram of the ammonia compressor shown on page 135, it will be found that the pump A compresses the vapour into the coils of the condenser B in which it is liquefied, and a very little ingenuity would enable anyone having a knowledge of these things to collect the liquefied product in cylinders. Under the ordinary temperature of the cooling water in the condenser the liquefaction of ammonia gas takes place under a pressure of between seven and eight atmospheres absolute, and



the apparatus employed for this purpose will give us a good insight into the *modus operandi* of all similar operations. Such an apparatus for making anhydrous liquid ammonia is shown in Fig. 123. The raw material employed is an aqueous solution of ammonia of a sp. gr. of 0.908, which is usually produced from a column still (Fig. 125), and condenser of adequate dimensions. The solution of ammonia is placed in the still upon the extreme left of the illustration, in which it is heated and the gas thus liberated is passed through a cooling worm, and from thence through a cooling cylinder before it enters the compressor. In this way nearly the whole of the moisture accompanying the gas from the still is deposited. In some cases, the gas is further dried by passing it over lumps of quicklime in a strong vessel, but usually this operation is omitted, as it has been found by experience, that with proper cooling in the last cylinder, the proportion of water in the liquid ammonia is very small indeed. It will be noted that the cooling water is made to enter the cooling cylinder first, and is then conducted into the vessel in which the coil is placed. It is a good plan to use all the water required for the steam boilers in this way, so as to ensure a good supply at all times for the purpose of cooling the coils. In this way the employment of an excessive current of water is not felt financially.

After the cooled gas has entered and left the compressor, it is passed through another cooling coil shown on the right of the illustration, in which it becomes liquefied, and finds its way into the strong egg-shaped receiver resting on the floor of the house, and which is sometimes also water-cooled. This second coil cooler takes up the heat of compression, and requires an ample supply of water, which, as a rule, cannot be employed again, as it will have been warmed during its passage through the vessel, and it is a *sine qua non* that the temperature of this water should not be allowed to rise unduly. It will thus be seen that the operation of compressing ammonia is a simple one, though it demands extreme care in attention to details. If the temperature of the cooling water in the last vessel rises unduly, the power required for liquefaction will rise also, and a reference to Table 20 will show that the pressure at 10° C. of 4,570 mm. will rise to 6,390 mm. if the cooling water should be allowed to rise to 20° C.

The compression of chlorine to the liquid state furnishes us with another illustration of how such operations require modification according to the physical and chemical characteristics of the material operated upon. The illustration (Fig. 124) shows the apparatus used by the Badische Anilin and Soda Fabrik to secure supplies of liquid chlorine.

The body of the compressing pump, shown at the extreme left of the illustration, is furnished with an enlargement which forms one limb of a U tube, and in this portion of the apparatus a plain or solid plunger operates. The lower part of the branch contains rectified sulphuric acid in which chlorine gas is nearly insoluble. Above the sulphuric acid, between this and the plunger, is a layer of petroleum, which lies chiefly in the enlarged portion of the barrel. The right-hand branch of the U tube communicates as shown with a reservoir, a back-pressure valve intervening, and connected by a straight side channel, which is closed and opened by a needle-valve,

and at the lower part it is connected to the source of dry chlorine by an inlet valve. When the plunger is worked in the ordinary way the chlorine gas is drawn through the sulphuric acid, and pressed into the upper reservoir, in communication with the cooler of coil type, as already described in the compression of ammonia gas, from which it flows into the reservoir, in which it is collected. The right-hand branch of the pump-tube is surrounded by a hot water jacket to prevent the chlorine from liquefying in the strong sulphuric acid. The reservoir in the top of the apparatus is provided with a water gauge as shown, in order to be able to ascertain the height of the acid contained within it, so as to ensure the safety of the operation. A small

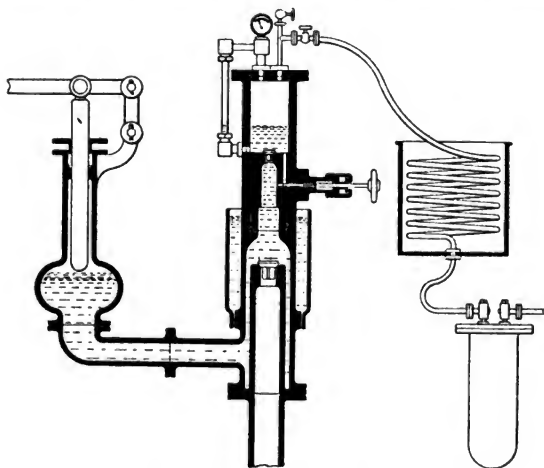


FIG. 124.—APPARATUS FOR LIQUEFYING CHLORINE.

quantity of chlorine may remain in the body of the pump, at the end of the downstroke of the plunger, and at the return stroke this highly compressed gas expands, and would stop the operation if means were not taken to prevent any such mishap. To prevent this happening, the small lateral channel is left slightly open by proper regulation with the needle-valve already mentioned, so that a small quantity of sulphuric acid enters the body of the pump from the upper reservoir each time the plunger is raised, and the sulphuric acid thus introduced is made to expel the last traces of chlorine; thus the operation can be continued.

The preparation and compression of liquid sulphurous anhydride is a large industry in Upper Silesia, where the factory Lipine turns out over

1,300 metric tons (1,000 kilos.) annually, the cost of the installation being over £13,000. In this instance, the SO_2 is prepared from the operation of blende roasting by the process patented by Messrs. Haenisch and Schröder, in 1883. A similar process is also worked by the Somerset Chemical Co., of New Jersey, U.S.A., but the source of the sulphurous anhydride is brimstone, burned in air. The gases from blende roasting seldom contain more than 7.0 per cent. of SO_2 by volume, so that when the compression of so much inert gas is considered, it will be at once apparent from what has been already said upon the power required for compression that to use these roaster gases direct would hardly be a profitable industry. There is some doubt as to whether the alternative method now to be described is satisfactory from a financial point of view, but it is certainly a more feasible proceeding than the compression of impure roaster gases, and the principles embodied in the operations being applicable to other processes it may be as well to examine them closely.

The Haenisch and Schröder process, already mentioned, consists in absorbing the sulphurous anhydride from impure roaster gases by means of water, in heating the acid solution so as to expel the dissolved gas, to wash, cool and dry the gas, and to then compress it in an apparatus very similar to that already illustrated under the head of liquid ammonia, on page 244. The processes necessary prior to compression differ much from those necessary for the preparation of liquid ammonia, and must be described in detail, the illustration, Fig. 125, aiding the description. The operation could not possibly be successful financially unless the heat of combustion is fully utilised, and to this proviso the apparent complication of the apparatus is due, as in plain words its success depends upon the efficiency of the heat-exchanging appliances.

Sulphurous anhydride is fairly soluble in cold water, and sparingly soluble in boiling water. At 0°C . one volume of water will absorb 68 volumes of the gas, but at 20°C ., the temperature at which it leaves the absorbing tower, one volume only absorbs 36 volumes. If we state the case in percentages, water at 20°C . contains 8.6% of sulphurous anhydride, while at 100°C . it will only contain 0.1%, so that if water saturated at 20°C . be heated to 100°C ., 88 per cent. of it will be expelled if the operation be conducted in a rational manner.

The burners for the blende or other raw materials need not be further described, as that has already been done in Chapter I. The hot gases leave the burners at a temperature bordering on 500°C ., and the first thing to consider is, how to fully utilise this heat of combustion, and so deliver the gases in a cool state into the absorbing tower. In the plant shown in Fig. 125, the roaster gases are passed under a leaden pan containing the solution from the absorbing tower, but which has first been pre-heated in another way, presently to be described. The result of heating this solution to 80°C . is the expulsion of the major portion of the anhydride, which moves forward a stage nearer the compressor. The gases are now cooled, and enter the absorbing tower in which they ascend, meeting water on their way upwards, and the water absorbing the sulphurous anhydride, the small quantity of

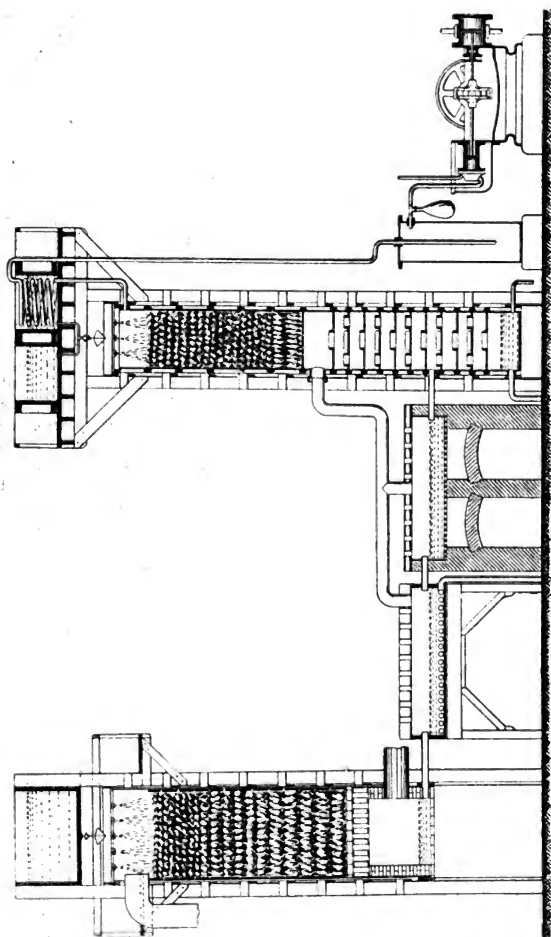


FIG. 125.—HAENISCH AND SCHRIEDER'S APPARATUS FOR THE ABSORPTION AND COMPRESSION OF SULPHUROUS ANHYDRIDE.

sulphuric anhydride and various other matters finds its way out of the foot of the tower into a preliminary heater, where it is warmed by the boiling water flowing from the desulphuriser. The waste gases consisting of nitrogen and oxygen pass away from the tower by a pipe at its summit.

The solution leaving the pan at 80° C. now enters the desulphurising column, where it is heated with live steam to 100° C., the spent water flowing through the pre-heater, where its heat is imparted to the cold solution of sulphurous anhydride running from the absorption tower. At 80° C. the solution still contains 1.7 per cent. of sulphurous anhydride, so that about 1.6 per cent. is expelled in the desulphurising column. There is but little to describe in the construction of the absorption tower; it may be filled with small coke (3-inch cubes), or with any of the packing materials that have been described in the early portion of this chapter. The heat exchanging apparatus, too, is open to many forms of construction, but the desulphurising column belongs to a form of apparatus that has yet to be described in the next chapter. The liquor running from the pan or last heater finds its way into this column about half-way down the series of plates with which the lower portion of the column is packed, while the gas from the pan and pre-heater is conveyed some distance above the liquor inlet, so that the gas from the pan mixes with the gas from the boiling liquor, and travel together through the packing which fills the upper part of the column. In this apparatus, the sulphurous anhydride and water vapour travelling upwards meet a small flow of cold liquor passing downwards, with the result that the upper portion of the tower or column is highly charged with cold sulphurous anhydride containing but a small quantity of water vapour, and practically no other impurity save traces of oxygen and nitrogen, which dissolve in the water of the absorption tower. The cold sulphurous anhydride is then passed through a cooling worm, and a drying tower, in which the packing is moistened with strong sulphuric acid, from which it is led to the compressing pump, not shown in the illustration. This example is deserving of careful study, as it may give many hints to other industries.

The carbonic acid gas industry is another example of a manufacture the financial success of which is dependent upon economical devices for the exchange of heat. Coke properly burned, and the gases washed free from impurities, produces carbonic acid gas, which is absorbed in a cold solution of sodium carbonate. Sodium bicarbonate is thus formed, the solution of which is heated above the point whereat it becomes decomposed, carbonic acid gas is evolved which is washed, scrubbed, and dried, and finally compressed much in the same way as already described for sulphurous anhydride. The solution of mono-carbonate of soda left behind in the decomposer is used again and again.

Before closing the subject of compression, some reference should be made to the regenerative method of liquefying gases, such as nitrogen and oxygen, and the production of liquid air. In practice, it is generally assumed that if no external work be done in the expansion of compressed air, the final temperature after expansion, when all parts of the system have attained

equilibrium, will be equal to the initial temperature, and no cooling will be effected. This, however, is not strictly correct, as with air compressed to 75 atmospheres upon one side of a valve, becoming reduced by expansion to 25 atmospheres on the other, the initial temperature being 10°C. , the air should be cooled through 12.7°C. by the expansion. Prof. Linde produced a machine for liquefying air, by utilising the cold produced from its expansion after compression, as early as 1895, the earliest trials being made at the testing station of the Linde Refrigerating Machine Co., at Munich. The

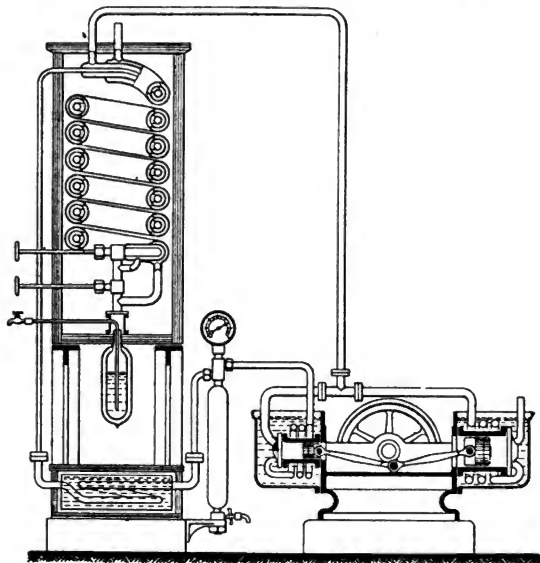


FIG. 126.—LINDE'S LIQUID AIR APPARATUS.

liquid contained 70 per cent. of oxygen, and calculations made at the time showed that one horse-power hour should give about 35 cubic feet of 70 per cent. oxygen in the liquid state. At the present time, a syndicate, exploiting the patents of Prof. Pictet, is manufacturing liquid air at the works of Messrs. Galloway's, Ltd., in Manchester, the compressors being run by electric motors, and it is asserted that the cost does not exceed half-a-crown per thousand cubic feet of oxygen measured in the gaseous state under the usual temperature and pressure. With a very large plant, working under the most economical conditions, it is expected that this cost could be much reduced.

We may now examine the principles of the regenerative method, in which an inspection of the illustration (Fig. 126) will help us. The illustration shows the construction of one of Prof. Linde's earlier machines. The air from the compressor is first cooled to eliminate the heat of compression, the cooling agent in the Munich trials being an ammonia freezing machine, but now ordinary water cooling is employed. The tube-system in which the actual work is done consists of a set of three concentric tubes in coil form placed in a carefully insulated chamber. The compressor forces the air under a pressure of 200 atmospheres into the innermost tube of the system. The air is then allowed to expand into the space between the central tube and that next to it, where the pressure is reduced to about 15 atmospheres. This expansion reduces the temperature as already explained, and the expanded air finds its way back to the compressor, where it is again compressed to 200 atmospheres. The central space in the tube system, in which the pressure is fixed at 16 atmospheres, is provided with a needle valve, where some of the air at this pressure is allowed to pass into the space between the outer and middle tubes, and this escapes into the air by the outlet shown projecting through the top of the insulating chamber in the illustration. The gas is thus further cooled, and so, as the compressor is kept working, the temperature becomes lower and lower, until the critical temperature of air is reached, and liquid air collects in the reservoir placed to receive it. Prof. Ewing stated, in "Engineering," page 310, 1898, that a plant was being erected at the Rhenania Chemical Works, at Aachen, by the Linde Company, with a capacity of 50 kilos. of liquid air per hour, for which a compressor of 120 horse-power was being provided. This works out to 1,447 cubic feet of free air per hour, and therefore to 0.08 horse-power per cubic foot of free air, so that if we compare these figures with those given in Table 19, on page 227, it will be seen that a very efficient steam motor will have to be provided in order to realise the projector's anticipations. In connection with this subject, the following table (21), showing some physical constants of the more common gases, may be found useful.

TABLE 21.

SHOWING SOME PHYSICAL CONSTANTS OF THE MORE COMMON GASES.

	Critical Temp. °C.	Critical Pressure. Atmos.	Boiling Point. °C.	Freezing Point. °C.	Authority.
Ammonia	+ 130°	115	— 33.7°	— 75°	Dewar
Carbon dioxide	+ 31°	75	— 78°	— 65°	Andrews
" monoxide	— 141°	36	— 190°	— 207°	Wroblewski
Chlorine	+ 141°	83.9	— 36.6°	— 102°	Dewar
Hydrogen	— 220°	—	— 238°	—	Dewar
" sulphide	+ 100°	92	— 61.8°	— 85°	Dewar
Nitrogen	— 146°	35	— 194°	— 214°	Olszewski
Oxygen	— 118°	50	— 183°	—	Wroblewski
Sulphur dioxide	+ 155.4°	78.9	— 8°	—	Sagotschewski

It has been already mentioned that a very little ingenuity will enable anyone having a knowledge of these things to collect the liquefied gas in cylinders. Such an operation must not, however, be undertaken without due study and caution. One of the earliest applications of compressed gases was in the direction of ballooning, and the compression of hydrogen was carried on upon an extensive scale at Chatham as long ago as 1885. Cylinders of compressed hydrogen formed part of the war material of the Soudan campaign. At this factory, the workmen had become very expert in the business of compression, but when very high pressures were employed, a foreman of the establishment lost his life while attempting to fill a cylinder from a reservoir in which the gas was under a pressure of about 100 atmospheres.

In dealing with compressed gases, almost the only precaution necessary is to see that each cylinder is strong enough to bear whatever pressure is likely to be put upon it, leaving, of course, a good margin for safety, and avoiding impact in filling; but when we have to deal with liquefied gases there are other precautions that have to be taken. Take, for instance, the case of liquefied sulphur dioxide, which has now become a very large industry. In the first place, the German regulations say that the cylinders must be tested up to a pressure of 30 atmospheres, although, if we turn to Table 20, we shall find that the tension of the gas at 25° C. is only 2,920 mm., or less than four atmospheres. Then, again, the cylinders must not be filled with liquid to more than seven-eighths of their capacity, so as to allow for gas-room and expansion. An interesting paper on this subject appeared in the *Zeit. angew. Chemie*, page 511, 1903, by A. Lange, in which several tables were given referring to the filling of cylinders of 10 kilos. capacity, with carbon dioxide, ammonia, sulphur dioxide, and chlorine, possessing volumes of 13.4 litres, 18.6 litres, 8.0 litres, and 9.0 litres respectively.

Most of the cylinders in which compressed gases are transported are made in Germany, and are imported into England for this purpose. The smaller sizes are well known, but sizes to hold 10 cwts. of liquid sulphurous anhydride are very common in the former country. For road and rail transport, as much as three tons of liquid sulphur dioxide are sent in single cylinders. Each cylinder is 20 feet in length by 27 inches in diameter, and three of these placed in a waggon make up a 10-ton load. In these cylinders, as in the smaller ones, there must be 12½ per cent. allowed for gas-room, or, in other words, each hundredweight of liquid dioxide should be allowed 1.5 cubic feet. Each vessel is fitted with a pressure gauge, and must be tested, previous to use, to from eight to nine atmospheres.

All these cylinders may be filled very simply from a reservoir of the liquid acid on a higher level by remembering that the filling pipe from the higher reservoir must be placed so as to conduct the liquid to the extreme depth of the vessel to be filled, while at the same time communication must be established from the gas-room of the lower vessel, which is being filled, to the gas-room of the higher or feeding reservoir. There may, of course, be many modes of carrying this out in practice.

CHAPTER IV.

EVAPORATION AND DISTILLATION.

The subject matter of this chapter can be treated most satisfactorily by arranging it under the heads of Drying, Evaporating and Distilling. Before proceeding further, however, we must have a good general idea of what is understood by these three terms, so that we may be able to place the various operations treated upon in their correct class.

Under the head of Drying may be classed such operations as the dissipation of moisture from spent dye-woods, the drying of grains, glue, and other materials, or the preparation of soap-shavings previous to plodding and compressing into tablets. The operation of drying does not deal alone with the dissipation of water. In such processes as the extraction of oils from crushed seeds, the residuum after the oil has been extracted is saturated with the solvent, and it is quite as correct to speak of the removal of this solvent as a process of drying, as if the meal had been left saturated with water.

When it is necessary to remove a liquid from a solid dissolved in it, when the solid portion is the part required, and the recovery of the liquid is of no moment, the operation is generally termed one of Evaporation. As a rule, water is the solvent, and the vapour produced is allowed to escape into the atmosphere; but when the evaporation takes place in a closed vessel, and the vapour is condensed and collected, we call the operation one of Distillation.

Drying may take place at the ordinary temperature of the air, but as it is greatly accelerated by the application of heat, it is usually effected at higher temperatures, unless the application of heat be injurious, which is sometimes the case. The drying operation in the preparation of glue is a case of this kind. The glue stock after clarification is concentrated by various methods, being finally drawn off from the pans into what are technically termed "coolers," in which it again settles. Here it also cools and partly solidifies into a soft pulpy jelly somewhat similar to the calves'-feet jelly of the shops, but darker in colour. This jelly, when properly set, is carefully taken out of the coolers and cut into slabs with a thin wire, and these are placed on a framework of netting in the open air to dry. The stack of nets upon which the slabs are placed is covered by a Λ shaped roof to keep off the rain, and to guard against the presence of the direct rays of the sun. In dry situations, the operation may be carried on for about eight months in the year, but the process is attended with many

risks. Should the sun perchance to strike the cakes of jelly while they contain water, they will probably melt and run through the netting on to the slabs below, or they may dry so quickly as to prevent them contracting to the proper size without the formation of numerous cracks and fissures, which spoil the look of the product. Once the cakes are sufficiently dry,

TABLE 22.

SHOWING THE TENSION OF AQUEOUS VAPOUR.

°C.	mm. Mercury.	°C.	mm. Mercury.	°C.	mm. Mercury.	°C.	mm. Mercury.
0	4.600	17	14.421	34	39.5	67	204.0
0.5	4.767	17.5	14.882	34.5	40.6	68	213.2
1	4.940	18	15.357	35	41.8	69	222.7
1.5	5.118	18.5	15.845	36	44.3	70	232.6
2	5.302	19	16.346	37	46.8	71	242.9
2.5	5.491	19.5	16.861	38	49.4	72	253.5
3	5.687	20	17.391	39	52.1	73	264.6
3.5	5.889	20.5	17.935	40	55.0	74	276.0
4	6.097	21	18.495	41	58.0	75	287.9
4.5	6.313	21.5	19.069	42	61.1	76	300.2
5	6.534	22	19.659	43	64.4	77	312.9
5.5	6.763	22.5	20.265	44	67.8	78	326.1
6	6.998	23	20.888	45	71.4	79	339.8
6.5	7.242	23.5	21.528	46	75.2	80	353.9
7	7.492	24	22.184	47	79.1	81	368.6
7.5	7.751	24.5	22.858	48	83.2	82	383.7
8	8.017	25	23.550	49	87.5	83	399.4
8.5	8.291	25.5	24.261	50	92.0	84	415.6
9	8.574	26	24.988	51	96.6	85	432.3
9.5	8.865	26.5	25.738	52	101.5	86	449.6
10	9.165	27	26.505	53	106.6	87	467.5
10.5	9.474	27.5	27.294	54	111.9	88	486.0
11	9.792	28	28.101	55	117.4	89	505.0
11.5	10.120	28.5	28.931	56	123.1	90	524.8
12	10.457	29	29.782	57	129.1	91	545.1
12.5	10.804	29.5	30.654	58	135.3	92	566.1
13	11.162	30	31.548	59	141.8	93	587.8
13.5	11.530	30.5	32.463	60	148.6	94	610.2
14	11.908	31	33.405	61	155.6	95	633.3
14.5	12.298	31.5	34.368	62	162.9	96	657.1
15	12.699	32	35.359	63	170.5	97	681.7
15.5	13.112	32.5	36.370	64	178.4	98	707.0
16	13.536	33	37.410	65	186.6	99	733.1
16.5	13.972	33.5	38.473	66	195.1	100	760.0

they are threaded on strings and hung up in rooms to harden, a process the length of which depends entirely upon atmospheric conditions. This primitive process is gradually being superseded by more scientific methods, whereby the drying operation is more under control, and in which the requisite conditions can be obtained to a nicety. The modern method is to place the slabs after being cut as just described, on to frames or shelves

with bottoms formed of netting and wire ; these are then placed in a drying room, where a large volume of dry warm air is made to circulate by means of a fan. Dryness of the air is of much more importance than a high temperature, and it will be found that the principles which govern these operations are all to be found in the present chapter.

Drying by means of a current of air depends chiefly upon its degree of humidity, that is to say, upon the proportion of moisture it has already taken up. Air will only take up a certain amount of moisture, and this amount may be readily calculated by reference to Regnault's tables of the tension of aqueous vapour at different temperatures. This is the maximum quantity of moisture that the air will take up, but the actual quantity present at different times must be found in another way.

Table 22 (after Regnault) will show us the tension of aqueous vapour for each degree Cent. expressed in millimetres of mercury. If we desire to know the temperatures on Fahrenheit's scale we shall find them on referring to Table 67, p. 181, Vol. I., and the millimetres of mercury may be converted into inches of mercury by Table 56, p. 177, of the same volume.

In nature, air is never quite dry, and only seldom is it found completely saturated with moisture. In England, the moisture varies between 70 per cent. and 90 per cent. of the quantity necessary to saturate it, the yearly mean being about 80 per cent., while the average of the different months, near London, is about as follows :—

January	89	July	76
February	85	August	77
March	82	September	81
April	79	October	87
May	76	November	89
June	74	December	89

In order to find the amount of moisture in the air, we must make use of the "wet and dry bulb hygrometer," and by means of the following table (23) the relative humidity and other conditions may readily be ascertained from the difference in the readings of the two thermometers. The first column represents the temperature of the air shown by the dry bulb, while the remaining columns give the pressure of the aqueous vapour in millimetres corresponding to the difference in the reading of the two thermometers. The second column headed by zero shows the amount of moisture when the air is saturated, or, when there is no difference in the readings of the two thermometers.

Suppose we wish to know the amount of moisture in the air when the dry bulb shows 20° and the wet bulb 16°, a difference of 4° ; if we follow the horizontal line at 20° we find under column 4, 14·9, which is the actual pressure of the aqueous vapour in millimetres. If now we wish to express the percentage humidity, we divide this number, 14·9, by the figure standing opposite 20° in column 0. In this case, the result will be :—

$$100 \times 14 \cdot 9 \div 17 \cdot 4 = 85 \cdot 6 \text{ per cent.}$$

The dew point may also be found by noting the temperature at which the observed moisture (say 14.9 mm.) would saturate the air. In this instance it will be seen to become saturated at 17° C.

TABLE 23.
FOR THE CALCULATION OF MOISTURE IN AIR.

°C.	0	1	2	3	4	5	6	7	8	9	10
0	4.6	4.0	3.4	2.8	2.2	1.6	1.0	0.4	0.1	—	—
2	5.3	4.7	4.1	3.5	2.9	2.3	1.7	1.1	0.5	0.1	—
4	6.1	5.5	4.9	4.3	3.7	3.1	2.5	1.9	1.3	0.7	0.1
6	7.0	6.4	5.8	5.2	4.6	4.0	3.4	2.8	2.2	1.6	1.0
8	8.0	7.4	6.8	6.2	5.6	5.0	4.4	3.8	3.2	2.6	2.0
10	9.2	8.6	8.0	7.3	6.7	6.1	5.5	4.9	4.3	3.7	3.1
12	10.5	9.8	9.2	8.6	8.0	7.4	6.8	6.2	5.6	5.0	4.4
14	11.9	11.3	10.7	10.1	9.5	8.9	8.3	7.6	7.0	6.4	5.8
16	13.5	12.9	12.3	11.7	11.1	10.5	9.9	9.3	8.7	8.0	7.4
18	15.4	14.7	14.1	13.5	12.9	12.3	11.7	11.1	10.5	9.8	9.2
20	17.4	16.8	16.2	15.5	14.9	14.3	13.7	13.1	12.5	11.9	11.2
22	19.7	19.0	18.4	17.8	17.2	16.6	16.0	15.3	14.7	14.1	13.5
24	22.2	21.6	20.9	20.3	19.7	19.1	18.5	17.9	17.2	16.6	16.0
26	25.0	24.4	23.7	23.1	22.5	21.9	21.3	20.6	20.0	19.4	18.8
28	28.1	27.5	26.9	26.2	25.6	25.0	24.4	23.7	23.1	22.5	21.8
30	31.5	30.9	30.3	29.7	29.0	28.4	27.8	27.2	26.5	25.9	25.3

It is a well-known law, that when a gas is saturated with vapour, the actual tension of the mixture is the sum of the tensions due to the gas and vapour separately, and when the gas is only partially saturated, each element in the mixture exerts the same pressure as it would exert if the other elements were removed. Knowing this, it is easy to calculate, not only the weight of a given volume of moist air, but the exact weight of moisture contained in it. The problem of finding the weight of a given volume of moist air may be conveniently divided in two parts—(a) the weight of the dry air at the temperature T and at the pressure $H-f$, and (b) the weight of the aqueous vapour at the temperature T and the pressure f .

We then have for a , per cubic foot at 0° C. :—

$$0.0864 \times \frac{273}{273 + T} \cdot \frac{H-f}{760} \quad (a)$$

which gives the weight of the dry air in pounds, the temperature T being expressed in degrees Centigrade, and the values of H and f in millimetres of mercury. The weight of the aqueous vapour (b) may be obtained from the following formula :—

$$0.623 \times 0.0864 \times \frac{273}{273 + T} \cdot \frac{f}{760} = \text{lbs. per cubic foot.} \quad (b)$$

The sum of the two foregoing weights is the weight of a cubic foot of moist air required. With saturated air the tension f may be obtained from Table 22, but when the degree of humidity is unknown, it must be ascertained by means of the hygrometer as already described.

The object of heating the air employed for drying is to render it capable of taking up more moisture than it would do in its natural state. Thus, for instance, air at 0° C. may, by Table 22, take up moisture until the tension of the vapour has risen to 4·6 mm., when it will take up no more at that temperature. If now we heat this air to say 90° C., we put it into a condition to absorb vapour until a tension 524·8 mm. has been arrived at, so that its humidity is now :—

$$\frac{4 \cdot 525 \times 100}{524 \cdot 8} = 0 \cdot 86 \text{ per cent.}$$

If the air be saturated with moisture at 15° C.—as it is on many a November day—the 100 of humidity is brought down to

$$\frac{12 \cdot 677 \times 100}{524 \cdot 8} = 2 \cdot 4 \text{ per cent.}$$

by heating it to 90° C.

On page 443 of Vol. I. some particulars are given of the Blackman air propeller. This appliance is employed for drying glue and many other substances, where a current of warm air is necessary. Let us suppose a fan to be employed passing 1,000 cubic feet of air per minute, entering the fan at 10° C., saturated with moisture, and leaving the drying chamber at 35° C., also saturated. The tension of aqueous vapour at 10° C., by Table 22, is 9·165 mm. of mercury, while at 35° C. it is 41·8 mm., so that the 100 of humidity has been reduced to 21·7 by heating from 10° C. to 35° C.

Let us now see what weight of water enters with the air, and also what weight leaves the drying chamber. The formula (b) gives us for 10° C. :—

$$0 \cdot 623 \times 0 \cdot 0864 \times \frac{273}{273 + 10} \cdot \frac{9 \cdot 165}{760} = 0 \cdot 00058 \text{ lb.}$$

as the weight of water in one cubic foot of air, saturated at that temperature ; and

$$0 \cdot 0864 \times \frac{273}{273 + 10} \cdot \frac{760 - 9 \cdot 165}{760} = 0 \cdot 0768 \text{ lb.}$$

for the dry air contained in it. We also find for 35° C. :—

$$0 \cdot 623 \times 0 \cdot 0864 \times \frac{273}{273 + 35} \cdot \frac{41 \cdot 8}{760} = 0 \cdot 00245 \text{ lb.}$$

of moisture, and the weight of dry air is :—

$$0 \cdot 0864 \times \frac{273}{273 + 35} \cdot \frac{760 - 41 \cdot 8}{760} = 0 \cdot 0676 \text{ lb.}$$

Moreover, the volume has been increased from 1,000 cubic feet to :—

$$\frac{1,000 \times 0 \cdot 0768}{0 \cdot 0676} = 1,136 \text{ cubic feet.}$$

So that we have :—

$$\text{Leaving : } 0 \cdot 00245 \times 1,136 = 2 \cdot 78 \text{ lbs.}$$

$$\text{Entering : } 0 \cdot 00058 \times 1,000 = \cdot 58 \text{ lbs.}$$

$$\text{Carried away per minute : } 2 \cdot 20 \text{ lbs.}$$

or 132 lbs. per hour.

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The following table, 24, showing the number of grains of water contained in each cubic foot of saturated air, may possibly be found of use in many calculations where the Fahrenheit thermometer is used.

TABLE 24.

SHOWING THE NUMBER OF GRAINS OF WATER IN EACH CUBIC FOOT OF SATURATED AIR FROM 32° F. TO 150° F.

°F.	Grains.	°F.	Grains.	°F.	Grains.
32	2·13	54	4·72	76	9·64
33	2·21	55	4·91	77	9·96
34	2·29	56	5·11	78	10·32
35	2·38	57	5·24	79	10·62
36	2·47	58	5·38	80	10·96
37	2·54	59	5·56	81	11·30
38	2·65	60	5·77	82	11·65
39	2·75	61	5·90	85	12·43
40	2·85	62	6·17	90	14·38
41	2·97	63	6·36	95	16·60
42	3·09	64	6·58	100	19·0
43	3·20	65	6·80	105	22·0
44	3·32	66	7·06	110	25·48
45	3·40	67	7·31	115	30·0
46	3·56	68	7·59	120	35·0
47	3·64	69	7·76	125	38·0
48	3·77	70	7·98	130	44·0
49	3·90	71	8·24	135	50·0
50	4·09	72	8·51	140	56·0
51	4·23	73	8·78	150	70·0
52	4·38	74	9·06	160	90·0
53	4·54	75	9·30	170	112·0

Three distinct periods may be noticed in the operation of drying by means of a current of warm air. In the first stage all the heat carried in by the air is employed in heating up the matters to be dried. In the second stage the air escapes, saturated with moisture, at a temperature which increases within certain limits according to the temperature at which it enters the apparatus, and when a certain maximum has been attained, the saturated air temperature remains constant until the third stage is reached. This third period is that in which the desiccation is being completed, and the air escapes only partly saturated, gradually rising in temperature until it reaches, within a few degrees, the temperature of the ingoing air.

In the author's laboratory there is a desiccator for drying large samples of wood pulp weighing up to over 20 lbs. in weight. These sometimes contain as much as 10 lbs. of water, and as this oven was specially constructed for the purpose, perhaps an examination of the principles may not be out of place here.

Let us suppose the air of the laboratory to be 10° C., and for the sake of simplicity let us suppose it to be saturated with moisture. One cubic foot of such air will contain :—

Moisture	0.000582 lb.
Dry air	0.076827 „
or 0.00757 lb. of water per 1 lb. of dry air.	

If now the air leaves the desiccator at 50° C., half-saturated with moisture, it will contain :—

Moisture	0.00255 lb.
Dry air	0.0642 „
or 0.0397 lb. of water per lb. of dry air.	

It is evident, then, that every pound of air on its passage through the apparatus has taken up $0.0397 - 0.00759 = 0.03213$ lb. of water, so that to drive off 10 lbs. of water we shall require 311 lbs. of air, or 4,039 cubic feet at 10° C. Now to evaporate 10 lbs. of water from 10° C. will require (see page 247, Vol. I.) $10 \times (637 - 10) = 6270$ c.h. units, and, the specific heat of air being 0.238, this is equal to the heat required for raising the temperature of $6270 \div 0.238$ or 26,344 lbs. of air 1° C. But according to the first part of the calculation we need only 311 lbs. of air, which must therefore be heated by

$$\frac{26344}{311} = 85^{\circ} \text{C.}$$

above the temperature of the entering air, so that if the air enters the heating apparatus at 10° C. it should leave at 94° C. to enter the drying chamber. As a matter of fact, if it could be made to enter at 10° C. and leave at 100° C. the operation would be much more quickly and economically performed.

It is here shown that 311 lbs. of air at 94° C. coming into contact with 20 lbs. of wet wood-pulp are cooled down to 50° C., and the heat thus parted with serves to evaporate the 10 lbs. of water.

This may be regarded as the minimum heat required, as the 10 lbs. of dry pulp that is left in the desiccator requires heating to 50° C., and the 311 lbs. of air has also to be heated to the same temperature. By this time practically the whole of the water has been driven off, and the temperature of the dry pulp will rise rapidly to near 100° C. in a current of air of the greatest dryness, thus ensuring the carrying off of the whole of the moisture.

As a matter of practice, when the air enters the drying chamber at 94° C., the pulp becomes quickly heated to about 55° C., and this temperature remains constant for some hours, the air leaving saturated at this temperature, but when the moisture is not coming forward quickly enough to saturate the air current, the temperature gradually rises until the air leaves at a temperature which is identical with that of the ingoing air.

There are many forms of dryers in the market, but want of space will not allow their illustration. One form, however, deserves special notice and illustration, and this is the "Geisenheimer" oven, used in France and Germany for drying and preserving fruit and vegetables for the market. An illustration of this dryer may be seen in Fig. 127, which shows it in section.

The apparatus is simplicity itself. It consists of an iron casing, in the lower part of which is placed a cast-iron "gilled" stove of small dimensions using coke as fuel. At about the centre of the chamber, above the stove,

is fixed an air distributor, which ensures an even flow of hot air through the trays above. The cold air entering the casing around the stove becomes heated by contact with the gills, while the products of combustion pass away by the smoke pipe shown at the side of the apparatus. The shelves which occupy the upper portion of the chamber consist of perforated and corrugated trays, which are placed one above the other in such a manner as to offer as little resistance as possible to the flow of an intense current of air heated to about 94°C. , in which the drying operation takes place very

rapidly. In the apparatus shown in the figure, the trays are so arranged that the whole of them, with the exception of the lowermost one, may be lifted by the simple pulling over of a handle, after which it is possible to slide out this and lower the remainder, so that each tray in turn becomes the lowest in the series. This is necessary, owing to the fact that the contents of the lowermost trays are dried much more quickly than those above them. The drier, as illustrated, consisting of 13 trays, weighs about 4 cwts., the height is nearly 8 feet, and its cost in London £17. 17s. It is stated that this machine burns 4 lbs. of coke per hour, and will dry 180 lbs. of whole apples in four hours, which quantity it will take in at one filling. The drying of plums seems to be a slow business, as it takes 16, 18, or even 20 hours to dry each filling of the apparatus.

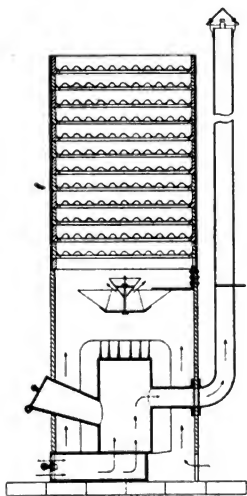


FIG. 127.—THE GRISENHEIMER DRYER.

Drying by means of direct fire heat, as distinguished from hot-air drying, is not always a satisfactory proceeding, neither is it always econ-

omical—though there are many cases in which this method may be employed. On pages 82 and 83 may be seen illustrations of the Bowers' continuous retort, and it has also been mentioned there that it makes a good dryer, especially when waste heat is employed, as the temperature can be modified to any extent required. It must, of course, be provided with flues, both for bringing in warm dry air and for taking away the moisture. Most dryers have special uses, and the special circumstances of each case will have to be taken into consideration in making a selection.

Let us take, for instance, the drying of superphosphates, wood chips, sawdust, bones, starch waste, grains, coal-dust, peat and many other

substances, it will readily be seen that precisely the same method could not be followed in each case. With each material to be dried, it should first be decided whether it be permissible or not to bring the products of combustion in direct contact with it. If it be permissible, then the revolving cylinder offers many advantages not to be found in many other appliances. The cylinder is placed at an inclination as already described (page 98) for the rotary calciner, the material is fed inside of it, and the fire gases suitably diluted with air, so as to secure a current of air at the required temperature, are sent through on their way to the chimney. Dryers for the purpose of desiccating superphosphates are now in general use on the Continent, but in this country they are not common, as the raw material used here generally contains sufficient carbonate of lime to secure the withdrawal of the excess moisture soon after the charge has been mixed. It is when "supers" are made with weaker acid than is generally used in Great Britain that the necessity for artificial drying comes in, and the operation must be effected with due consideration of all the circumstances of the case in order to produce satisfactory results. At first sight it would appear immaterial whether the fire gases travelled along in the same direction as the "super" to be dried, or in the contrary direction, but in practice it is of the greatest importance. With superphosphates, and, in fact, with all the substances just mentioned, a comparatively low temperature must be employed, say, 200°C. , for the sake of illustration. If the products of combustion entered the drying cylinder at this temperature, where the dried material was discharged, a very large percentage of the soluble phosphate would be rendered insoluble, but if the products of combustion entered at 200°C. , at the higher end of the cylinder, it will be found that the dried material seldom exceeds a temperature of 86°C. , which is a rather beneficial temperature than otherwise. The drying of wet combustible matters comes also under the same category. The spent grains of the brewer or distiller will withstand a temperature of 200°C. when they are saturated with moisture at the commencement of the drying operation, but it would not do to expose them to such a heat when nearly dry.

The construction of apparatus of this type is simple in the extreme, and does not require special illustration. The cylinder is placed at a small inclination, and the products of combustion carried through it, or in some cases the heated gases are confined in a casing around the cylinder, so that they may not come in contact with the material to be dried. The interior of the cylinder is often provided with longitudinal webs similar to the breakers of a revolver. These carry up the partly dried material and allow it to drop through the current of heated gases, and allow of a more ready exit for the moisture than if the material lay closely upon the bottom of the cylinder. The illustration of the rotary sand dryer shown by Fig. 46, on page 99, will give the reader a good idea of the construction of this form of apparatus. It will at once be manifest that the foregoing apparatus and process described could scarcely be employed where extreme cleanliness was a *sine qua non*, such as the drying of soap chips for the manufacture of

toilet soaps, the drying of albumen, glue, starch, gelatine, drugs, etc., and for such purposes a current of air heated by means of steam pipes is very often employed. It has already been shown that a Green Economiser may be used to furnish the hot air (page 58), abstracting at the same time the heat from the waste gases in the boiler flues, but where this is not possible a special air heater is often used. Soap tablets and soap chips can be dried much more readily in a current of warm air than by the old system of steam-heated drying rooms, and the same system may be applied to a variety of substances, but in every case great care must be taken to ensure an even distribution of the air within the chamber, and never to allow it to become saturated with moisture. This is especially the case with crystals containing water of crystallisation. The illustration (Fig. 128) shows a drying chamber for soap chips and similar substances fitted with the Seagrave-Bevington air heater, as made by Messrs. W. J. Fraser and Co. for tobacco-leaf drying.

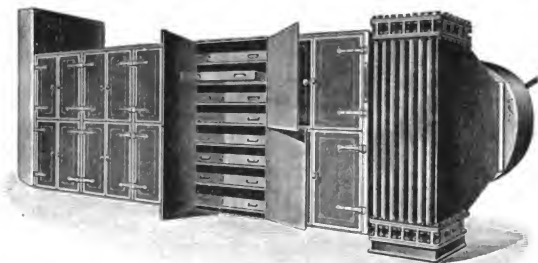


FIG. 128.—DRYING CHAMBER FITTED WITH THE SEAGRAVE-BEVINGTON AIR HEATER.

Drying is sometimes effected *in vacuo*, and this method offers some substantial advantages, as, if required, the temperature employed may be less to secure the same evaporation as at the normal air pressure, or, for the same temperature, a much more rapid drying will take place. Under a vacuum of 28 inches of mercury water boils at 38° C., and the boiling points at other reduced pressures may be seen in Table 84, p. 250, Vol. I.

The following illustration (Fig. 129) shows the construction of a vacuum drying chamber made by Emil Passburg in Berlin. The figure shows a chamber with the door open exposing the shelves to view.

The box or chamber is of cast-iron, fitted also as shown with cast-iron shelves, through each of which hot water or steam can be made to circulate, being connected to the steam main, or to a hot water main by means of the small pipes shown at the right hand of the figure. The door is closed by means of screw tighteners, a ring of india-rubber cord serving to make the joints air-tight. The top of the chamber is connected with an air pump (vacuum), which draws out the vapour as fast as it is formed. A vacuum

oven of this pattern with 11 shelves, each measuring 40 in. by 35 in., and placed 4 in. above each other, will occupy a ground space of 6 ft. by 4 ft., and contains 243 sq. ft. of heating surface. Its cost is about £155, to which must be added £35 for a "dry" air pump necessary to work it. From some very careful experiments made with this vacuum dryer, it appears that one pound of moisture can be driven off from wet materials, with 1.2 lb. of steam, which includes the steam necessary for driving the vacuum pump, when the exhaust steam is employed for heating. The

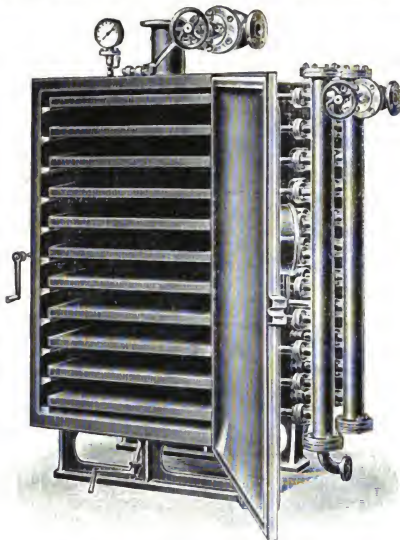


FIG 129.—VACUUM DRYING CHAMBER.

vacuum system of drying is especially useful where volatile solvents have to be removed, as the recovery of them is rendered much more easy by adopting the process.

Before leaving the subject of drying, it may be as well to refer again to the drying out of volatile liquids from the substances absorbing them. Methylated spirit and methyl alcohol are largely employed in hat finishing, acetone in the manufacture of explosives; benzine or petroleum spirit is also employed in the "dry-cleaning" of clothing, while benzol, carbon di-sulphide, carbon tetra-chloride, chloroform, and ether have each their special uses.

In order to arrive at some idea of the rate of evaporation of these liquids, samples were exposed to the still air of the laboratory and weighed after definite intervals. The results may be seen in Table 25.

TABLE 25.

SHOWING THE EVAPORATION IN GRAMMES PER SQUARE FOOT PER HOUR OF EXPOSED SURFACE.

(Temperature 18° C. Humidity 66 per cent.)

Liquid.	1st Hour.	2nd Hour.	3rd Hour.	4th Hour.	5th Hour.	6th Hour.
Acetone	144	96	95	96	94	80
Alcohol*	56	48	46	46	42	47
Benzine**	224	128	126	124	80	64
Benzol	80	72	68	66	66	64
Carbon disulphide	288	266	256	244	230	224
„ tetra-chloride	176	143	127	127	128	97
Chloroform	224	208	209	208	208	192
Ether	384	360	288	272	232	203
Wood naphtha†	80	66	64	65	55	48

* Ordinary methylated spirit.

** Petroleum ether 0·665 sp. gr.

† Ordinary miscible wood naphtha.

The numbers in Table 25 are much larger during the first hour than during any hourly period afterwards; this is due principally to the fact that the evaporation started with the liquid practically at the same temperature as that of the surrounding air (64·2° F.), but after the lapse of one hour the temperature of the liquid was much less than that of the atmosphere, owing to the heat being absorbed during evaporation. For instance, the ether experiment started with a temperature of 18° C., at the end of the first hour the liquid in the copper dish was 12° C., and at the end of the second hour, 10° C., while at the end of the third hour the temperature had fallen to 7° C., which continued until the end of the sixth hour, when the experiment was finished.

Irregularity of composition and its effect upon evaporation may be seen in the fifth and sixth hours. Liquids with a smaller vapour tension were undoubtedly present in each case. Thus, with benzine, which is really a mixture of heptane and hexane, with other hydrocarbons in small quantities, the rate of evaporation during the second, third and fourth hours was very constant, but when the bulk of the lighter hydrocarbons had gone, the reduced vapour tension of the remainder had a considerable effect upon the rate of evaporation. That this was really so may be inferred from the fact that the original ether put out for evaporation had a sp. gr. of 0·721 at 18° C., while the 10 per cent. left unevaporated at the end of the experiment possessed a sp. gr. of 0·777 at the same temperature. The wood-spirit started with a sp. gr. of 0·823, and the residue at the finish (only 30 per cent. having evaporated) was 0·846 sp. gr.

The next Table (26) will enable us to calculate approximately the weight of any liquid which will be evaporated at given temperatures, from a given surface in still air. The rate at which evaporation proceeds in still air depends upon the vapour tensions of the liquids at the given temperatures, and upon the amount of moisture the air has already absorbed. By the aid of information supplied in Tables 22 and 26, we are able to arrive at very close figures for ordinary temperatures by the following very simple rule :—

$$E = (F - f).$$

Where E is the amount of liquid in grammes, evaporated from a surface of one square foot, per hour ; F , the vapour tension of the liquid, at the given temperature expressed in millimetres of mercury ; while f is the actual vapour tension of the moisture present in the air at the time.

TABLE 26.

SHOWING THE VAPOUR TENSIONS OF SOME LIQUIDS.
(Millimetres of Mercury.)

°C.	Acetone.	Alcohol.	Benzol.	Carbon Disulphide.	Carbon Tetrachloride.	Chloroform.	Ether.	Methyl Alcohol.
-20	—	3.4	5.8	47	9.8	—	69	6
-10	—	6.4	13	79	18.5	—	115	13
0	60	12.7	32	128	33	—	184	27
10	110	24.2	45	199	56	160	287	50
20	180	44.5	76	298	91	247	423	89
30	280	78.5	120	435	142	370	635	150
40	420	134	184	617	215	535	907	244
50	603	220	271	857	315	755	1265	382
60	860	350	390	1164	448	1042	1725	580
70	1189	541	547	1550	621	1407	2305	857
80	1611	813	752	2030	843	1865	3023	1240
90	2142	1189	1013	2620	1122	2430	3900	1740
100	2797	1697	1340	3320	1467	3110	4950	2400
110	3594	2368	1715	4160	1887	3930	6210	3260
120	4547	3232	2235	5150	2394	4880	7720	4340

Let us take a case in point. Acetone, exposed to the still air of the laboratory, of a temperature of 18° C. and 66 per cent. humidity, should lose per square foot per hour exposed :—

$$E = 160 - 10 = 150 \text{ grammes per sq. ft.}$$

Experiment gave 144 grammes. Again, ether exposed to similar conditions should lose :—

$$E = 396 - 10 = 386 \text{ grammes per sq. ft.}$$

while actual experiment gave 384 grammes.

This method of dealing with the subject is, however, not quite parallel to actual practice. If a porous substance has absorbed a quantity of volatile liquid, it is more than likely that the operator will desire to know in what time

the absorbed liquid will be dissipated, rather than to be told that the liquid itself will give off a certain weight of vapour in a given time. Take for instance a thick felt saturated with acetone; experiment showed that one square foot saturated with the liquid and exposed to air of a temperature of 20° C. parted with 1,782 grains as vapour during the first hour, 184 grains during the second hour, and 18 grains during the third hour. The following Table (27) gives the results of some experiments upon the drying of one square foot of ordinary woollen cloth, after saturating with the various liquids and wringing dry by hand, the air temperature being 16° C. with 60 per cent. humidity.

TABLE 27.

SHOWING THE EVAPORATION IN GRAMMES FROM ONE SQUARE FOOT OF CLOTH WEIGHING 48·0 GRAMMES.

	Dry and Wet Bulbs. °C.	Weight of Liquid Absorbed. Grammes.	First 50% evapor't'd in minutes.	Last 10% evapor't'd in minutes.	Total time drying. Minutes.
Acetone	16°.11°	52	6	6	16
Alcohol (methylated)	16°.12°	60	25	75	118
Benzene	16°.11°	64	8	8	22
Benzoline	16°.11°	32	2	2	6
Carbon disulphide	16°.12°	80	4	6	14
„ tetra-chloride	16°.12°	104	5	11	18
Chloroform	16°.11°	92	4	3	11
Methyl Alcohol	16°.11°	56	19	41	86

Evaporation.—Though evaporation generally may be taken to mean the dissipation of all kinds of liquids when made to assume the vaporous condition, the practical process of evaporation as carried on in a chemical works is generally taken to refer to the removal of water from aqueous solutions. This kind of evaporation may be divided into two classes—"over-heat" and "under-heat," as they have been commonly called.

In what is known as over-heat evaporation, the fire gases are made to pass in contact with the liquid to be evaporated, and, in the ordinary way of performing the operation, is a very inefficient process. Over-heat evaporation may be divided into several classes, according to the manner in which the heat is brought in contact with the liquid, and hence we have (a) the ordinary over-heat pan, in which the heated gases—the products of combustion usually—are made to pass over the surface of the liquid lying quiescent upon the floor of the pan in which it is contained. The old black-ash pans of the alkali makers were of this description, and also the antiquated pans of the vitriol maker. Then we have a second class (b), in which surfaces of incorrodible material are moistened with the liquid to be evaporated, as in Gossage's evaporator, or the "Glover tower," and, finally, we have a third system (c), wherein the liquid is thrown up in the form of a

spray, through which the products of combustion are passed, as illustrated by the Porion evaporator.

Under-heat evaporation, though capable of many different forms of arrangement, varies chiefly in the nature of the heating medium, and the devices necessary in accordance therewith. Thus we may have pans or other vessels heated by gas, liquid fuel, coal, coke or steam, and the construction will vary accordingly.

What has already been said on the first page of the present volume relating to solar evaporation, taken with the remarks and rule on that page, will amply suffice for a full understanding of that subject, and no more need be said except to point out that wind has a very great influence upon the rapidity of evaporation, and this is also the case with air currents in covered pans.

Let us now examine the case of one of the old over-heat black-ash pans. An ordinary black-ash furnace (see page 14, Fig. 3) would have a pan attached to it 16 ft. in length and 8 ft. in width. This pan was nearly filled with black-ash liquor, and over the surface the waste heat of the furnace was passed. Experience had shown that a pan of these dimensions would just boil down to salts all the liquor produced from the black-ash balls made in the furnace. Per day of 24 hours a furnace of this kind would turn out 24 black-ash balls, each containing 3 cwt. of salt-cake; there would be 2.16 tons of firing slack used, and 1.8 tons of mixing slack. The volume of vat liquor put into the pan per day would be 311 cubic feet, containing 18 lbs. of dry soda-ash to the cubic foot, while 7,663 lbs. of salts were drawn daily, containing 25 per cent. of water. A very simple calculation will show us that 16,637 lbs. of water were evaporated per day over the area of 128 square feet, which is 5.4 lbs. per square foot per hour. Now as to the water evaporated per pound of fuel. Without any serious error, all the heat of the firing fuel and half that used for "mixing" will be available for evaporative purposes; this is 6,854 lbs. per day, so that the 16,637 lbs. of water evaporated daily will amount to 2.4 lbs. of water per pound of fuel. The ordinary over-heat vitriol pans were of the foregoing type, but they have for the most part disappeared, and more efficient apparatus has taken their place.

The "Kessler" sulphuric acid concentrating plant, which is shown in section by Fig. 130, must not, however, be confounded with the ordinary over-heat pan, although it bears some resemblance to it. It is really a combination of the principles of the over-heat pan with that of the Glover tower, and means are taken in the construction to make each stage efficient. The acid to be concentrated lies about six inches deep upon the floor of the chamber S, having passed downwards through the plateaux D, C, B, and A, the acid level upon the floor being maintained by means of the overflow pipe *m*. The hot products of combustion from a coke fire enter at O, and before they reach that portion of the apparatus marked O', they are compelled to pass through a shallow layer of the surface acid lying in the pan, as shown by the arrows *i, i, i*. The walls that are built up in the pan are shown in plan by Fig. 131, which will show more clearly than the first

illustration how this is brought about, and a further reference to Fig. 132 renders it quite clear that the heated products of combustion enter the chambers $q\ q\ q$, and pass into the channels $q'\ q'\ q'$, from thence into O' , and finally into the recuperator which extends from O' to Z . The recuperator is made of several acid-proof basins, and porcelain pieces are fitted to holes bored in them, so as to force the gases in the pan to pass through a shallow layer of the acid, and when they escape from the top dish of the recuperator they are highly charged with the abstracted moisture. The construction of the lower basins of this part of the apparatus may be seen by Fig. 132,

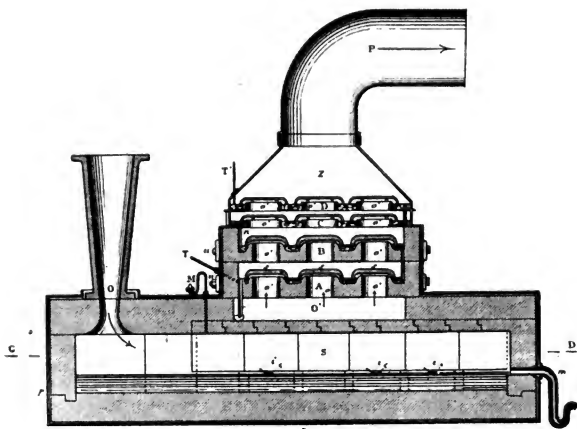


FIG. 130.—KESSLER'S CONCENTRATING PLANT.
(Longitudinal Section.)

and upon an enlarged scale in Fig. 133, the plan of which is very similar to that of the gas washer shown in Fig. 101, page 212. The top plateaux C and D may be of lead, as the temperature at that point is not high, and the apparatus is fed there with the weak acid to be concentrated, and the top plateau D also receives the weak acid coming from the coke scrubber or condenser. The combined acids find their way down from dish to dish of the recuperator, until they reach the acid lying upon the pan floor.

The hot acid is cooled by means of a stream of the cold acid to be concentrated, while the gases partly saturated with moisture are drawn off by means of an exhauster and forced into the "separator" or coke scrubber, which is worked at such a temperature that while the sulphuric acid spray

is condensed, the gases are still saturated with moisture when they leave the scrubber.

The Kessler apparatus, when making 93-94% acid, consumes about

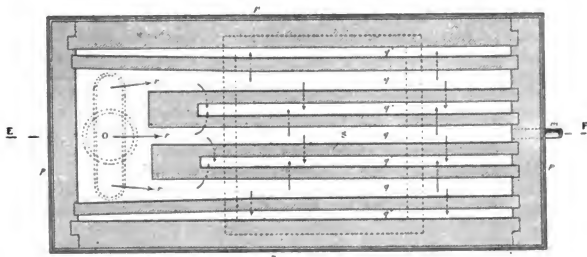


FIG. 131.—THE KESSLER CONCENTRATOR.
(Plan.)

2 cwts. of coke in the generator, and about 2 cwts. for the souffleurs or exhausting apparatus, say, 4 cwts. in all, but when 96% acid is worked for, the generator or gazogene will consume 3 cwts. of coke and 4 cwts. of coal for the souffleurs. The apparatus is, so far, the best that has been devised for the concentration of weak sulphuric acid, but there is still ample room for invention and economy, as the evaporation of water is but small, varying from 2.0 lbs. to 3.4 lbs. per pound of coke used, according to the strength of acid made.

The regulation of the air supply to the gazogene of the Kessler plant, requires considerable attention in order to avoid destruction of the lining, which would certainly take place were the carbon of the coke oxidised to carbonic acid within it. If the carbon were burned to carbon monoxide, with only 10 per cent. oxidised to carbonic acid, the theoretical temperature of combustion would be about 1640° C. In reality it would be less than this, as considerable losses by radiation take place; but if the carbon be burned

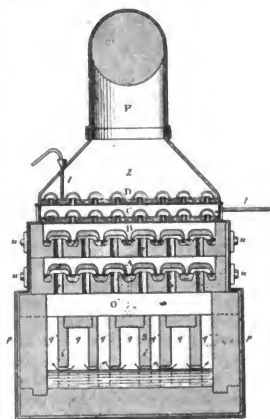


FIG. 132.—THE KESSLER CONCENTRATOR.
(Cross Section.)

in the gazogene with just the quantity of air necessary to form carbon dioxide, the temperature developed would be $2630^{\circ}\text{C}.$, which would be destructive even to the best fireclay, working under similar conditions.

One great drawback to the Kessler system is the large quantity of weak acid obtained from the condenser. In a recent plant, making 12 tons of 96% acid per day, the weak acid amounts daily to seven tons at $60^{\circ}\text{Tw}.$, which has to be reconcentrated. Another drawback lies in the necessity for providing a fairly pure acid, otherwise the sulphate of iron and sulphate of alumina become insoluble as the acid increases in strength, and so chokes the saturator and coats the various portions of the recuperator with a scale that is apt to be exceedingly troublesome. Glover-tower acid could not be employed in such an apparatus without some preliminary treatment.

The condenser employed in connection with the Kessler plant has already been described and illustrated. A plant producing 12 tons of 96 per cent. acid per day is at the moment of writing passing away from the

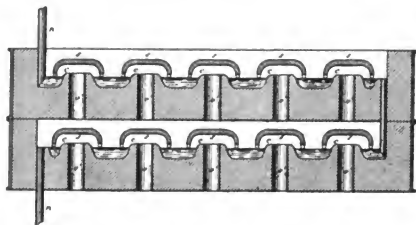


FIG. 133.—KESSLER'S CONCENTRATING APPARATUS.
(Section through Recuperator Dishes.)

condenser no less than 20,000 lbs. of steam, with the products of combustion, each working day of 24 hours. There is surely room for improvement here.

The second system, foreshadowed on page 266, was that of evaporation by bringing hot gases into contact with surfaces moistened with the liquid to be treated. This plan is not very generally adopted, save in sulphuric acid works where the hot gases from the kilns are passed upwards through the Glover tower, while the acids for denitration and concentration are made to percolate downwards through the filling material. The words "filling material" are used advisedly, as there is not any unanimous opinion as to what constitutes the best filling material. Flints, tower rings, blocks, balls, bricks, and even coke have been recommended for filling Glover towers, but there is no doubt that tower rings and balls will give the best results, as they expose more surface to the action of the gaseous current than most other materials. The following illustration will give a good general idea of the construction of the Glover tower or concentrating column.

The tower consists of a thick leaden shell lined internally with acid-proof bricks, or blocks of the same material. This lining is for the purpose of

protecting the leaden shell from the heat entering with the pyrites gases, and also from the corrosive action of the stream of sulphuric acid at high temperature. The lead work is usually made in three "lifts"—*i.e.*, pieces in height—the bottom "lift" being of very thick lead, usually three-quarters of an inch in thickness.

It will be seen that the tower framing is made to carry the weight of the leaden shell as well as the tanks and shed upon the tower top, which, together with the acid contained in the tanks, will all have to be taken into account when designing.

The interior of the tower is packed or filled with acid resisting bricks, flints, balls, or tower rings supported upon arch-blocks, such as are specially made for this purpose by the Buckley Brick and Tile Co. A tower 8 ft. 6 in. square—outside measurement—will suffice for 72 tons of pyrites weekly, which is one square foot of sectional area per ton per week; but as about one-half of this is dead space for some distance above the arch-blocks (the tower lining), it is better to take the measurement of the cross-section of the packing at that point, and to make this the basis for designing. At this point the available space within the tower lining is six feet square, so that the rule should be to provide half a square foot of packing immediately above the arch for each ton of pyrites burned per week. Care must be taken to provide an inlet and outlet for the gases of sufficient size, and to graduate the packing according to the work to be done. It would seem superfluous to insist upon such details, but the exhortation is often needed.

Let us now examine the working of an ordinary Glover tower, when we shall see what a heat waster it is when used as an evaporator, selecting for our illustration one designed for taking the gases from ten tons of Spanish pyrites per day.

It is usual, in most sulphuric acid works, to run down the tower a stream of acid equal to three times the daily make (in this case, 20 tons at 120° Tw. was the daily production); that is to say, all the acid made in the chambers, plus twice its bulk of nitrous-sulphuric acid, was passed down the tower, issuing from the bottom at a temperature of 154° C. A fair amount of heat is lost from the extended surfaces of the tower, and the gases escape from the top at about 82° C., carrying with them the water evaporated

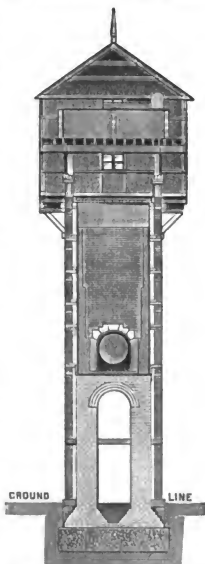


FIG. 134.—"GLOVER TOWER,"
OR DENITRATING COLUMN.

from the 20 tons of 123° Tw. acid in forming 148° Tw. acid. How much water is this? Twenty tons of 70 per cent. acid are equal to 17·5 tons at 80 per cent., so that the water evaporated per day will be 2·5 tons. The acid running out at the tower lip is approximately 60 tons daily at 154° C., and this is cooled down to 27° C., by passing through a water cooler at the foot of the tower.

It is easy to calculate approximately the quantity of cooling-water required. The 60 tons of acid entering the tower at 27° C., becoming 57·5 tons, and leaving at 154° C., will carry away :—

$57\cdot5 \times 2,240 \times 127 \times 0\cdot46 = 7,524,496$ C.H.U.
the specific heat of acid at this strength being 0·46.

We have two methods of calculating the heat leaving the tower in the acid; the one just described depending upon the weight and temperature of the acid itself, and the other in which the volume and temperature of the cooling water are noted. In the water cooler in which these experiments were tried, the water supply was 600 gallons per hour, which entered at 10° C., and left at 60° C., passing through 500 lineal feet of 1½ inch lead piping submerged in the acid. We have, then, by this method :—

$$600 \times 10 \times 24 \times 50 = 7,200,000 \text{ C.H.U.,}$$

a difference of about 5 per cent.

If we reckon that each pound of pyrites requires 6·0 lbs. of air for the ordinary combustion (80 cubic feet), and that the gases pass from the kilns into the tower at 500° C., their specific heat being equal to air, we shall find that this equals :—

$$11,200 + (2240 \times 10 \times 6) \times 500 \times \cdot 238 = 17,326,400 \text{ C.H.U.*}$$

The heat required to convert the 2·5 tons of water into steam is 3,111,000 C.H.U., and the heat carried away by the escaping gases amounts to 3,554,133 C.H.U., so that we may now summarise as follows :—

Heat units lost by hot acid	7,524,496 C.H.U.
Latent heat of evaporation	3,111,000 "
Heat in escaping gases	3,554,133 "
Leaving for radiation, etc.	3,136,771 "
Total heat entering tower	17,326,400 C.H.U.

This is perhaps a calculation that would not satisfy the theoretical physicist, as minute corrections have not been made, but it is quite sufficient for all those practical purposes for which this volume has been written.

The loss by radiation may, at first sight, appear excessive, but it only amounts to :—

$$\frac{3,136,771}{800 \times 24} = 163 \text{ C.H.U. per square foot per hour,}$$

the tower possessing a cooling surface of 800 square feet, which is probably not out of the way when it is remembered that Hurter found 76 Centigrade heat units to be dissipated per square foot per hour from an ordinary hydrochloric acid tower from which the acid was issuing at 80° C.

* No allowance has been made here for the absorption of oxygen by the Fe of the pyrites.

Many years ago the late Mr. W. Gossage devised a tower for concentrating sulphuric acid, which was a prototype of the Glover concentrator. Hot air was the concentrating agent, which was made to pass downwards through the tower, in the same direction as the acid undergoing concentration. The plan was, however, never adopted outside his own works, though a modified plant was erected and worked for some years at the Calder Chemical Co.'s works at Castleford. The hot products of combustion in this case entered the lower part of the tower, and left at the top, the gases and acid taking exactly the same course as in the Glover tower of to-day. Owing chiefly to faulty arrangements this installation was not found successful in practice, and was abandoned.

As a matter of fact, the Glover tower, though it be a good denitrator, cannot be styled an efficient evaporator, as it is ordinarily worked. The vapours driven off in the hot or lowermost portion of the tower have to pass through the top, or comparatively cold portion, in which they are to a large extent re-absorbed. These towers were once built to contain 24 feet depth of packing, and one was, to the author's knowledge, built in St. Helens, in 1876, with nearly 50 feet of packing, but the author's practice is to build them with only 12 feet of packing, which has been found better than when this limit is exceeded. It seems needless to say that the tower with 50 feet of packing had to be shortened to less than one half before it would work satisfactorily.

Gossage no doubt knew of this drawback, and so brought the hot gases first in contact with the cold acid, but this was not a practical cure for the evil. By turning to page 272 once more, we shall see that the heat passing away in the hot acid is much more than sufficient to heat up the whole of the acid introduced to above the boiling point of water, and it is a marvellous fact that this observation has never been utilised in the concentration of oil of vitriol.

Some twenty years ago the author made a series of experiments to determine at what temperatures sulphuric acid at various strengths began to lose water by contact with gases at the same temperature, and as these have not been published before, they may be of interest to the reader at this place, from which it will be seen that weak sulphuric acid may readily be concentrated in an ordinary leaden pan heated with a steam coil filled with low pressure steam, when the surface is freely exposed to the air, and the degree of concentration required does not exceed 150° Tw.

Acid of 150° Tw. began to lose water at 106° C.

"	140	"	"	80°
"	130	"	"	65°
"	120	"	"	50°
"	110	"	"	46°
"	100	"	"	37°
"	90	"	"	26°
"	80	"	"	19°
"	70	"	"	17°
"	60	"	"	16°

Other determinations have since been made at strengths varying from 160° Tw. to 166° Tw., the results of the whole series being shown on the annexed diagram (Fig. 135). At 60° Tw. sulphuric acid is a good hygrometer, losing water in a dry atmosphere and gaining it when the air is in a state of greater saturation.

We may now pass on to the third system of over-heat evaporation, with which the author has had very considerable experience, viz., the throwing

up of the liquid as a spray or rain shower, and sending the hot products of combustion through it. This is the essence of the well-known Porion evaporator which is shown in Fig. 136, being a reduction from the actual drawings of an apparatus designed by the author for the Calcutta Paper Mills Co. in India.

The evaporator which bears this name was designed by Mons. E. Porion, of Wardrecques, to deal with the spent wash of the distiller, using molasses for the production of spirit. After the fermentation and distillation the spent wash contains potash salts which the apparatus was intended to recover. The solution was, however, of such a degree of tenuity that ordinary methods of evaporation were not profitable, and hence only those methods were allowable in practice that could show more than 10 lbs. of water evaporated per 1 lb. of coal.

As may be seen from the drawing (Fig. 136), the apparatus consists of an ordinary re-

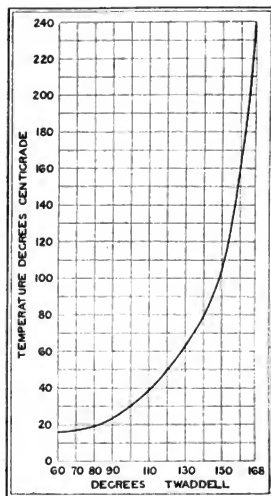


FIG. 135.—
DIAGRAM OF O.V. CONCENTRATION.

verberatory furnace, to which is attached, first, a combustion chamber, and finally an evaporating chamber, upon the floor of which lies the liquor that is being evaporated. Two sets of fanner blades running at about 300 revolutions per minute dip about an eighth of an inch into this liquor and raise it as a spray or rain shower through which the products of combustion pass on their way to the chimney. Waste paper mill liquor (esparto-liquor) has a density of about 8° Tw., and in this chamber it is concentrated to about 50° Tw. It is fed into the Porion chamber continuously from an overhead tank, and the concentrated liquor flows from the chamber in a continuous stream into a store tank placed over the rever-

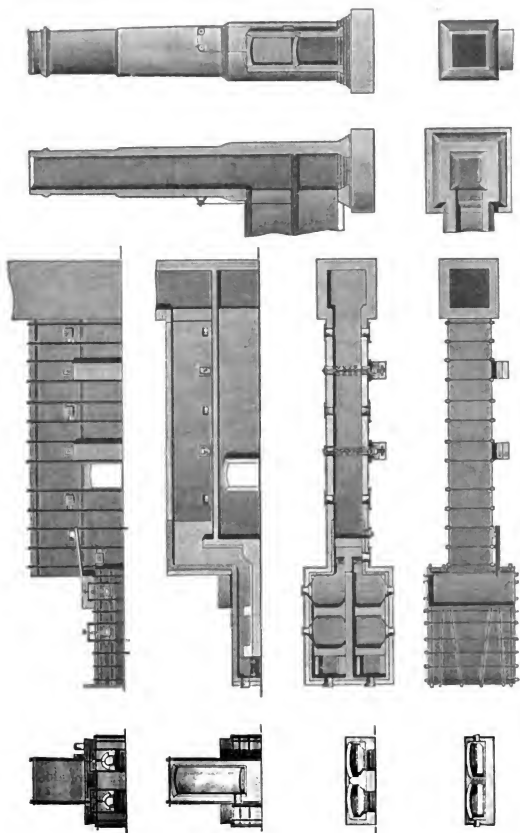


FIG. 136.—TIR FORION EVAPORATOR. (Designed for the Calcutta Paper Mills Company by Davis Bros.)

beratory furnaces, from whence it is withdrawn in charges to feed the hearths after the finish of each calcination.

The immense evaporative effect of this chamber may be appreciated when it is known that at the Inveresk Mills 24,000 gallons of lye are being concentrated daily to 5,700 gallons, at which point it is ready for the calciners. It is not policy to continue the concentration beyond 40° Tw. at 77° C., which is equal to 50° Tw., at a standard temperature of 38° C.

TABLE 28.

SHOWING THE COMPOSITION OF WASTE PAPER MILL LIQUORS.

(At 10° Tw. and 38° C. = 100° F.)

	Esparto.		Wood.		Straw.	
Soda-ash (46%)	5·0	4·9	5·4	5·7	4·7	5·2
Organic matter	6·0	5·9	4·2	4·8	6·6	5·6
Water	89·0	89·2	90·4	89·5	88·7	89·2
	100·0	100·0	100·0	100·0	100·0	100·0

When the charge is on the calciner bed the organic matter it contains is destroyed and takes fire, but in the ordinary way the combustion of these gaseous products is by no means complete, as in passing over the back bed the large amount of watery vapour present checks the combustion, so that if the gases from the beds were passed direct into the Porion chamber, a great deal of fuel material would be lost. This is the reason why the combustion chamber has been introduced, and that it assists in the economy of fuel there is but little doubt.

The amount of fuel used in the Porion furnaces naturally depends upon how much fuel matter there is in the liquid to be evaporated. With liquors similar in composition to the waste-paper mill liquor it requires about 32 cwt. of slack per ton of ash recovered from liquors at 8° Tw. at 38° C., or two tons of slack when the liquors are 6½° Tw. at 38° C. The actual wages for the calciners amounts to 5s. per ton of ash drawn, to which one shilling more should be added for incidental expenses.

From the analyses already given, it will be seen that ordinary spent lye from esparto boiling contains for every 100 parts of recovered ash certainly not less than 120 parts of organic matter. In some instances the proportion of organic matter is larger, but the foregoing figures are average quantities, and it is a speciality of the Porion system that it is able to employ this organic matter as fuel for the evaporation. It will be seen that this source of fuel is by no means an unimportant factor, as if the evaporation is calculated upon the coal consumed, the quantity may be expressed as 21 lbs., which it is well known cannot be the case, as we shall see presently.

With an ordinary Porion the use of a gas producer is to be avoided. Theoretically one would expect that 50 per cent. more fuel would be required with gas, as against coal, and this is the case in practice. There are two

Porions working, built from the same designs, so far as Porion chambers and furnace-beds are concerned, and it has been found that while the coal-fired evaporator uses 32 cwts. of slack per ton of ash recovered, the gas-fired installation consumes 49 cwts. This is only to be expected, as most of the heat of the carbon burning to carbonic oxide is lost, and though the author disapproved of the arrangement, it was proceeded with, giving the results already stated. It is pleasing to meet with a failure occasionally, as it gives experience that could not be obtained in any other way, and one often gains more experience from failures than from successes.

In making comparisons with what is being done in the various forms of evaporating apparatus in use, it is absolutely necessary to refer all densities to one standard temperature. Everyone will be aware that hydrometers should in ordinary cases be read at a temperature of 15.5°C. , but for the purpose of ascertaining the density of these waste lyes this temperature is inadmissible, as when esparto liquor has been concentrated to 40°Tw. at 80°C. , it is nearly solid at 15.5°C. , so that it is impossible to take the gravity with any approach to accuracy. At 38°C. , however, the solid mass retains its liquid form, so that this temperature has been selected as the best at which to take and refer all densities of such liquids. At the Inveresk Mills, the waste lye was going into the first pan over the combustion chamber at 11°Tw. , and 29°C. , and was running out of the pan to feed the evaporating chamber at $6\frac{1}{2}^{\circ}\text{Tw.}$ and 100°C. It was actually entering the evaporating chamber at 7°Tw. and 88°C. , and was leaving this chamber on its way to the furnaces at 32°Tw. and 76°C. Again, six months later, the whole of the processes were again examined; the waste lye going into the first pan was 10°Tw. at 38°C. , entering the evaporator $6\frac{1}{2}^{\circ}\text{Tw.}$ at 99°C. , and running from the evaporator to the furnaces at 40°Tw. and 77°C. By themselves, these figures serve only to mystify, but let us reduce them to the 38°C. standard, and look at them again in Table 29.

TABLE 29.
SHOWING THE WORK OF A PORION EVAPORATOR.

Description.	March.			October.		
	$^{\circ}\text{Tw.}$	$^{\circ}\text{C.}$	$^{\circ}\text{Tw.}$ at 38°C.	$^{\circ}\text{Tw.}$	$^{\circ}\text{C.}$	$^{\circ}\text{Tw.}$ at 38°C.
Entering first pan	$11\frac{1}{2}$	29°	11	10	38°	10
Feeding the Porion	$6\frac{1}{2}$	100°	13	$6\frac{1}{2}$	99°	13
Leaving the Porion	32	75°	42	40	78°	49

We can now see definitely what has happened. In March, the first pan was actually strengthening the liquor by 2°Tw. , as well as heating it to the boiling point, a fact it was impossible to ascertain by a simple inspection of

the former figures, and in October the pan was strengthening the lye 3° Tw. But at the standard temperature we are able to tell more than this, for not only has the pan over the combustion chamber materially aided the evaporation, but we have information also that the Porion chamber was evaporating this 13° Tw. liquor to 49° Tw.

A cross section of the Porion chamber may be seen upon a larger scale in Fig. 137, which is a cut through the centre of a fanner-blade shaft.

The illustration shows the almost indestructible nature of the apparatus (which is built of good bricks) and the position of the fanner blades in relation to the liquor and head space. As before mentioned (page 216), the fanner

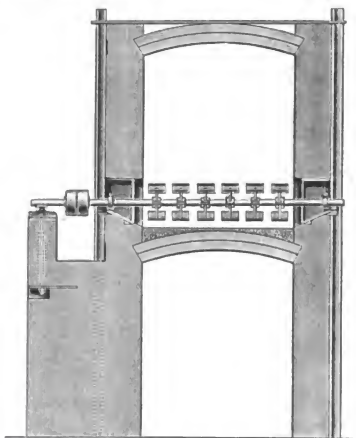


FIG. 137.—THE PORION EVAPORATOR.
(Section through Fanner Shaft.)

blades of a well-designed apparatus will take 5 H.P. to drive them effectively, but all depends, of course, upon the shape of these blades. They must produce the spray with as little friction as possible, and this result is only to be attained by careful attention to the edges of the blades. The exact construction of the blades may be seen by Figs. 138 and 139, which show one of them in section and elevation, taken from an actual working drawing.

The products of combustion enter the Porion chamber at about 500° C., or even more, and their temperature is *instantly* reduced to about 83° C. by contact with the water-spray. This is also the temperature of the liquor lying on the bed of the chamber, even though it be fed in continuously at 100° C.

Let us now see what happens during the working of this apparatus. Without sensible error, we may assume that every pound of coal burned in the furnaces will take in 300 cubic feet of air at 15°C ., or 22·8 lbs., and, as this leaves the evaporator at 83°C ., the volume will be increased to 420 cubic feet. The heat carried away by the air would therefore be approximately :

$$22\cdot8 \times 0\cdot238 \times 83 = 450 \text{ C.H.U.},$$

so that if we reckon one pound of good coal to yield 7,000 C.H. units, the heat used for the evaporation would be :—

$$7000 - 450 = 6550 \text{ C.H.U.},$$

or nearly 12 lbs. of water evaporated at 83°C ., from the temperature of 15°C .

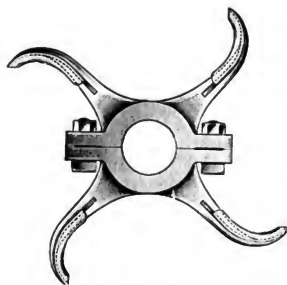


FIG. 138.
(Side Elevation.)

PORION FANNER BLADE.

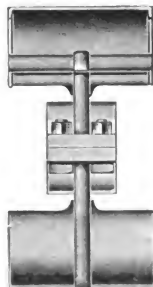


FIG. 138.
(Front Elevation.)

At 83°C . the volume of this vapour would be 600 cubic feet, so that the total volume of gases passing away by the chimney, per pound of coal burned, would be at 83°C . :—

Products of combustion	.....	420 cubic feet
Water vapour	.....	600 ,,
		<hr/>
		1,020 ,,
		<hr/>

If 25 tons of coal be burned in the furnaces per week of 168 hours, the volume of gases passing away per second would be :—

$$\frac{2240 \times 25 \times 1020}{168 \times 60 \times 60} = 94 \text{ cubic feet,}$$

say, 100 cubic feet per second. The chimney requisite for this size of evaporator is 7 ft. square and 56 ft. high—let us say 50 sq. ft. in area—so that the velocity of the draught would be equal to 2·0 ft. per second at 82°C .

M. Porion considered the 25,000 gallon evaporator quite large enough in practice, but in special cases larger chambers can be designed to meet

altered conditions. If the quantity of liquor exceeds 25,000 gallons daily more than one evaporator should be employed; in such a case the weak liquor should be fed into one of them, and the half concentrated liquor used in the other. The following table shows the capacity of the various sizes, their approximate cost, and the number of tons of ash they will recover weekly from paper mill lyes of various strengths:—

TABLE 30.
CAPACITY AND COST OF PORION EVAPORATORS.

Capacity in gallons per 24 hours.	Approximate Cost of Complete Installation.	°Tw. at 100° F. Tons per week of 40 per cent. Ash.								
		2°	3°	4°	5°	6°	7°	8°	9°	10°
5,000	£400	1	1½	2	2½	3	3½	4	4½	5
10,000	500	2	3	4	5	6	7	8	9	10
15,000	600	3	4½	6	7½	9	10½	12	13½	15
20,000	650	4	6	8	10	12	14	16	18	20
25,000	700	5	7½	10	12½	15	17½	20	22½	25

The cost of building an evaporator of this description will vary according to the locality in which it is erected; but as the major portion of the plant is constructed of common bricks the variation in price is not so great as may, at first sight, appear. The bulk of the ironwork consists of old railway metals, with which the furnaces are braced, the remaining expenses being but slight.

The author has designed many of these evaporators on Mons. Porion's lines, of capacities varying from 8,000 to 26,000 gallons per 24 hours. The apparatus is not, however, of universal application, but where it can be applied it can only be excelled by evaporators working under a vacuum, and with triple effect. In connection with the Porion evaporator one fact that forces itself on our notice is this—that notwithstanding the low temperature of the escaping gases and vapours, and the saturated condition of the products of combustion as regards moisture, there is plenty of draught in the chimney for the furnace fires—too much in fact, as the chimney damper is always partly closed, even though the chimney be used for the evaporator alone, and has no other heat passing into it.

Under-heat Evaporation.—In this mode of evaporating liquids the products of combustion are kept out of contact with the liquor undergoing evaporation, which is necessary in most cases, as the presence of the sulphurous acid in the fuel gases would deteriorate the product, and the fine coal-ash and soot would not improve the quality. The steam boiler, fully described in Chapter V. of Vol. I., is an excellent example of an under-heat evaporator, and we may learn much from it that will stand us in good stead when dealing with other forms of evaporators. The steam boiler is an

example of a closed evaporator, though its efficiency is in no way due to the fact that it is a closed vessel, but to the large extent of heating surface usually exposed per unit of fuel burned. There are many instances in practice in which evaporation in closed vessels is imperative, owing to the pungent and odorous qualities of the vapours evolved, such as in oil boiling, bone boiling, the concentration of size and of certain chemicals, but the bulk of chemical operations of this nature are usually carried on in vessels freely exposed to the air.

Let us now examine the details of evaporation in closed vessels and in open vessels, and see whether there are any lessons to be learned from them. The ordinary 30 ft. \times 7 ft. Lancashire steam boiler will, in every-day work, evaporate 6 lbs. of water from 10° C. per pound of good slack, and according to the details given on page 231 of Vol. I., the products of combustion have a run of 120 ft., and are in contact with 900 sq. ft. of heating surface, some parts of which, however, are less effective than others. In the early days of the caustic soda industry, and, in fact, as late as 1872, the weak washings from the caustic mud were, in some works, evaporated in the steam boilers, the steam being used for the general purposes of the works, the concentration continuing until the density of the liquor had risen to 35° Tw. or to 40° Tw. For many reasons this method was abandoned, but chiefly on account of the wear and tear produced by the impurities in the soda liquors. The action of the sulphide of sodium upon the rivet heads was so severe as to completely destroy the boilers, and several disastrous explosions occurring with this class of apparatus, led to its complete abandonment. Notwithstanding this experience, there are still many liquids that could be dealt with in the foregoing manner with success, if only scientific methods were followed, but it is certainly not a process for "rule-of-thumb."

Nothing could serve to illustrate the operation of evaporation in open vessels better than the methods used in the manufacture of salt. Here the finest or "butter salt" is made at a temperature near to the boiling point, and, as a general rule, the lower the temperature of the brine at which evaporation takes place, the larger is the grain of the salt produced. "Fishery salt" is made at low temperatures (about 43° C.), while the "common salt" of the chemical works is produced at a temperature between these two extremes.

The salt industry is able to furnish some valuable lessons to those who are willing and able to read them, not the least of which is the trouble and expense caused by the accumulation of impurities. The crude brine contains a certain quantity of sulphate of lime, only a small portion of which leaves with the deposited salt. When the pan fires are lighted, and the pan is new, the brine soon becomes hot, because this sulphate of lime has not commenced to deposit upon the plates. This state of things does not, however, last long; after a very short space of time thin films of scale commence to form immediately over the fires, and these gradually increase in thickness until the scale becomes so thick that scarcely any heat will pass through. At this stage a long pointed hammer called a "dodger" with a shaft 12 ft. in length is brought into use. While the fires are burning and

brine still in the pan an attempt is made to knock the scale off, which generally results in doing much damage to the pan bottom, as the "dodger" always loosens some of the rivets and opens the riveted seams, causing brine to escape and leak over the fires. Sometimes the leakage is so great as to extinguish the fires, but in ordinary cases the brine falling upon the fuel and evaporating in the heated flues in the presence of sulphurous acid gas causes the evolution of hydrochloric acid gas, which is emitted from the chimney, and is the cause of so much destruction to vegetation all round the neighbourhood of salt works. When a salt pan has been "dodged" and got fairly to work again it scales even more rapidly than before, as whatever scale is not removed the first time forms a nucleus for new scale, and in a very short time the salt-pan bottom is so much damaged that it has to be emptied and repaired. The cost of repairs caused directly by pan-scale is not less than 4½d. per ton on the amount of salt actually made, besides the loss of hot brine and the stoppage of the pans. With all these drawbacks on the present mode of making common salt, from 1·8 tons to 1·9 tons are produced from the combustion of one ton of slack.

An ordinary salt-pan will turn out from 40 tons to 50 tons per week, but one has been made to do 60 tons when clean, though this last amount cannot be styled the average. The usual pan measures 66 ft. in length by 24 ft. in width, and 20 ins. in depth. There are four fire places (each 4 ft. square) to each pan, upon which about 25 tons of slack are burned per week, or 6 lbs. per square foot per hour, so that 1·8 tons of salt are produced for each ton of slack. As full-strength brine is said to contain 22 per cent. of salt (2 lbs. 9 oz. per gallon), there will be seven tons of water associated with two tons of salt, so that the water evaporated per pound of slack amounts to about 6·4 lbs.

The foregoing figures as to the strength of brine are those usually accepted in Cheshire, but they do not accord with the author's analyses, which may be found in the next table.

TABLE 31.
SHOWING THE CONSTITUENTS OF NATURAL BRINE.
(Grammes per litre or ounces per cubic foot).

Locality	Sp. Gr. 15·5°C.	Sulphate of Lime.	Magnesium Chloride.	Sodium Chloride.
Northwich (a)	1·206	5·52	0·86	317·0
" (b)	1·206	5·55	0·94	316·9
Middlewich (a)	1·204	5·55	1·75	312·7
" (b)	1·204	5·56	1·78	312·8
" (c)	1·205	5·62	1·76	313·4
Lostock Gralam	1·202	5·53	0·83	307·5
Wincham Hall, Northwich (a)	1·206	5·40	0·86	313·0
" " " (b)	1·196	5·59	0·85	298·6
Winsford " "	1·202	5·55	1·80	309·7

With coarse fishery salt, which is made at lower temperatures than the foregoing, the output per pan is less than 20 tons per week, and the fuel consumption 12 tons, so that the fuel used in this case has produced the evaporative effect of 5·8 lbs. of water per pound of fuel burned. The gross surface of a salt-pan bottom is 1960 sq. ft., which is reduced by the thickness of the flue walls to 1300 sq. ft., so that when making 40 tons of salt per week, the water evaporated would be 120 tons or 1·23 lbs. per sq. ft. of heating surface per hour. A Lancashire boiler evaporating one ton of water per hour, with a heating surface of 947 sq. ft., will show an evaporation of 2·3 lbs. of water per sq. ft. per hour.

The instances already given are of pans with extended heating surfaces, and a long travel for the flame. When pans are short they are usually placed one behind another in series so as to utilise the heat as much as possible, but though it is necessary to do this sometimes on account of the special nature of the operation, it is a poor way of applying heat.

The form of the evaporating pans, the extent of their heating surface, and the nature of the material of which they are to be constructed must, of

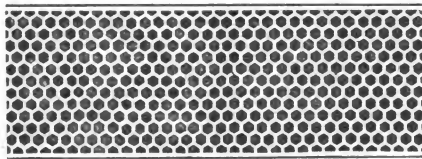


FIG. 140.—SUPPORTING-PLATES FOR LEADEN PANS.

course, depend upon the kind of liquid to be evaporated, so that it is impossible to treat this branch of the subject in general terms, but it is always easy from established precedents to determine the dimensions, heating surface, and general arrangement for each particular case.

Let us take as an instance the concentration of sulphuric acid, from, say, 100° Tw. to 150° Tw. in under-heat pans, a process that is certainly going out of use except for the concentration of dearsenicated chamber acid to brown oil strength. Here the materials of which the vessels are constructed may be either platinum, glass, porcelain, lead or iron, and, according to the material selected for construction, so must the plan of setting be varied. A leaden pan is usually supported over the heating flues upon solid iron plates from three-quarters of an inch to one inch in thickness; but it has been found better to eschew solid plates and to substitute perforated plates for them, such as shown in Fig. 140. These perforated plates allow sufficient support for the hot lead, and much more direct heat to pass to the heating surface of the pan than when solid plates are employed, and the lead lasts much longer when set in this way than when it is in direct contact with an unbroken surface of iron.

The pans required to do a certain quantity of work vary with the nature of the operation, and the figures on the diagram (Fig. 60), upon page 121, may be again studied with advantage. It may be that a large quantity of acid of moderate strength is only required to be concentrated a few degrees, or, acid of low strength requires concentration to a high strength. The first case happened in St. Helens in a works with which the author was once connected. The acid ran from the chambers at 130° Tw., and was boiled up to 140° Tw. in eight pans, only four of which were self-fired. Each pan exposed a heating surface of 60 sq. ft., and the whole series treated 100 tons per week at 130° - 140° Tw. This amounts to 4.8 sq. ft. of heating surface per ton per week, but these pans would have done more work, as the firing was very slow and moderate.

In another installation known to the author, two concentrating pans, each 24 ft. \times 6 ft., both self-fired, concentrated 28 tons per week from 100° to 152° Tw., which is 10 sq. ft. per ton per week. In an ordinary pan, 100 sq. ft. of heating surface will concentrate three tons of acid per day of 24 hours from 110° Tw. to 140° Tw., but when the plates have hexagon perforations, as shown in Fig. 140, 100 sq. ft. will concentrate at least four tons per day through the same number of degrees.

The remarks that have been already made upon the necessity for brisk agitation during the heating of liquids (page 123) apply with still greater force to the concentration of sulphuric acid in both over-heat and under-heat pans. Actual ebullition scarcely ever takes place, and the viscosity of the liquid seriously interferes with the exchange of heat. If, however, artificial agitation is applied the process of concentration will be much hastened, with perhaps a slight additional expense for fuel. In an ordinary underheated lead vitriol pan, the concentration takes place simply by reason of the contact of the surface of the acid with the atmosphere, which, if stagnant, is in a state of minimum efficiency, but if the atmosphere is frequently changed, and the acid be gently agitated, we shall have a twofold acceleration. In effect, the evaporation depends upon the vapour tension of the acid and the degree of saturation of the ambient atmosphere; the former is the result of temperature, which can be improved by making the exchange of heat between the acid and the heating surfaces more complete, while the latter may be brought to a maximum value by removing the moisture laden atmosphere before it has become saturated. It must, however, be recognised that to effect both of these objects a further expenditure of fuel is necessary, so that it becomes a matter of simple calculation how much can be afforded to secure the extra efficiency. We have already seen when considering the Kessler apparatus that it requires the steam from 4 cwts. of coal to work the souffleur designed to remove the moisture laden atmosphere coming from the production of one ton of 96 per cent. acid.

The injection of air into concentrating pans in which weak sulphuric is being evaporated has been a favourite subject with many inventors, but most of them have overlooked the real processes that go on. Reference to page 273 will show that sulphuric acid may readily be concentrated to 150° Tw. if kept at a temperature just above the boiling point of water, and a

current of air blown through it, but this is the highest gravity that can be so obtained at this temperature, but acid at 50° Tw. may be concentrated to 80° Tw. by treating it with a current of dry air at 20° C. Sulphuric acid may also be concentrated to 96 per cent. by treating it with a current of cold air if the temperature of the acid be maintained at 260° C. In an apparatus designed by the author for this purpose, 10 per cent. of the original acid (by volume) was driven off by the air current and was arrested in the condenser at 24° Tw., or, in other words, 320 cb. ft. of acid produced 280 cb. ft. at 96 per cent. and 30 cb. ft. at 24° Tw.

With pans of all kinds, waste heat can often be used for evaporative purposes by turning it underneath the pans in suitably constructed flues, and if the initial temperature is sufficiently intense a large proportion of the heat may be utilised. The waste heat from revolving black-ash furnaces was, in Allhusen's works at Newcastle-on-Tyne, turned under two pans, each

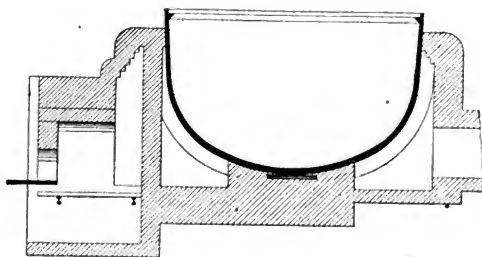


FIG. 141.—A CAUSTIC-POT SETTING.

44 ft. \times 20 ft., or a total area of 1760 sq. ft., and this surface was sufficient to concentrate the whole of the caustic liquor made from the black-ash of the revolver, from 20° Tw. to 50° Tw.

When the heating gases from a furnace encounter horizontal surfaces above them, we have, as a rule, the greatest heat-exchanging efficiency, but it is not always possible to construct apparatus in this manner, as there are many other points to consider which are quite as important as the economy of fuel. The ordinary caustic pot is an excellent example of this. In the final stage of the manufacture of caustic soda, the contents of the pot reach a very high temperature (a low red heat), and the pot requires to be of such design that it will not only boil down the strong aqueous solution, but also allow the anhydrous caustic to be fused in it. The platinum evaporating basin of the laboratory has by common consent become the established pattern for this class of operations, but the way in which its large scale relatives are set in the brickwork—with nearly vertical heating surfaces—does not conduce to economy of fuel.

The form and setting of these pots may be seen in Fig. 141, which has been made from the working drawings of a pot, 10 ft. in diameter, and 6 ft. 3 ins. deep, which, when full of fused caustic soda, will pack out nearly 18 tons at one finishing.

The fireplace is 3 ft. long by 2 ft. 6 ins. wide, and burns from 10 lbs. to 20 lbs. of slack per sq. ft. of firegrate surface per hour. The furnace would, of course, burn more than this, but the restricted heating surface necessitates using the damper pretty freely. The flame from the fireplace usually passes completely round the pot sides, and escapes into the flue at a very high temperature, especially when the pot is fusing, so in order to avoid this loss, it is usual to place a pot behind each pair of finishing pots to use up some of this waste heat. This pot is called a back pot, and is commonly set on the same principle as the front or finishing pots, but it would be much better—as there is no “finishing” ever done in them—to set all back pots in such a manner as to give more horizontal heating surface, and this might easily be done in the manner shown by Fig. 142.

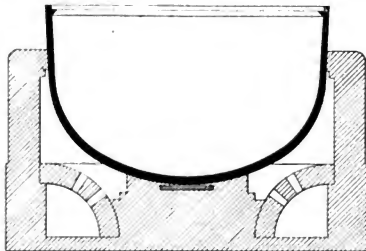


FIG. 142—SETTING FOR BACK-POTS.

Each finishing pot (with its share of a back-pot) is expected to pack once a week, when the back-pot is fed with liquor at 80° Tw., but this does not allow for stoppages. If the back-pot were fed with liquor at 100° Tw., the above estimate would be a good average figure, and the tear and wear and breakages would be less than when everything is rushed. Caustic liquor at 100° Tw. contains approximately equal weights of water and “fused” caustic, so that if a pot packs once a week, that is firing five days out of the seven, it is required to eliminate 17 to 18 tons of water in the five days, or, say, 39,200 lbs. in 120 hours. If the pot fire burns 20 lbs. of fuel per sq. ft. per hour, this amounts to 16,800 lbs. per week of 120 hours, or to 2.33 lbs. of water per pound of fuel. The moral of this is to do as little evaporating as possible in pots of this description, but to use pans of greater heating surface for this part of the operation. The latest development in industry is to evaporate the caustic liquor from 20° Tw. to 100° Tw. in triple effect vacuum pans, and to feed such liquor into the back-pots.

Notwithstanding the low evaporative effect of pots of this form, they are much used in several chemical industries where the use of cast-iron is a *sine quâ non*. In one work known to the author, where these pots are used to concentrate a solution for crystallising, 11,000 gallons of water are evaporated per week of 168 hours in three pots, each 8 ft. in diameter and 6 ft. deep, which amounts to 22 gallons per pot per hour. The fuel used is 17 tons weekly, which reckons out to 10 lbs. per sq. ft. of grate surface per hour. This is an evaporation of 3.0 lbs. of water per pound of slack fuel. These pots cannot be fired so heavily as in the caustic soda industry, hence the slightly superior fuel economy. Were they fired harder, the contents would boil over and be lost.

Pots of this shape in cast-iron are also much used for the concentration of strong oil of vitriol to 96%. At densities above 154° Tw. the action of sulphuric acid upon cast-iron is very slight if the operation is performed in a certain way. Several years ago, the author concentrated 40 tons of sulphuric acid weekly from 110° Tw. to 167° Tw., the later part of the operation being effected in cast-iron pots of the shape indicated in Fig. 141. The weak acid was first concentrated to 154° Tw. in a coke fired over-heated leaden pan, from which it was run while hot into the cast-iron rectifying pots, each holding about two tons of finished acid. Experience showed that heavy castings were not required, as the metal did not wear away evenly. Every pot in use broke down, not on account of any general solution of the metal in the acid, but by reason of the formation of large circular holes from one-quarter of an inch to one-half of an inch in diameter, which gradually but surely were eaten through the metal. Some pots would only contain one such hole, while others would contain several, but, of course, one such fault would be sufficient to throw the pot out of use.

During the ten months that the foregoing pots were in use, some valuable experience was gained, and the author was led to believe that lighter weight pots of cast-steel would have been much more successful. As it was, 93 per cent. acid could be obtained with the expenditure of 4 cwts. of coke per ton, and an ordinary foundry iron would last in use about eight months before the pots required changing. As each pot contained two tons of finished acid, and made four journeys per week, the total produce of one pot was about 250 tons, and as the pot weighed 25 cwts. the wear and tear amounted to just one shilling per ton.

A summary of results possible of attainment may now be drawn from the foregoing pages, which will serve to guide the designer in most instances without the trouble of intricate calculations.

If we take the Babcock boiler results mentioned on page 256 of Vol. I., we shall find that the 983 sq. ft. of heating surface evaporated 2,925 lbs. of water per hour, producing steam at 155 lbs. per sq. in. pressure, at a temperature of 187° C. Upon working this out, the student will find that the heat transmission is 1,916 c.h. units per sq. ft. per hour, which will guide him in all operations of a like nature.

Turning now to the results obtained from the Lancashire boilers (page 260, Vol. I.), we find that 4,736 sq. ft. of heating surface evaporated 23,429

lbs. of water to steam at 78 lbs. pressure or 161°C. , the temperature of the feed-water being 111°C. If we work this out, we shall find that the evaporation corresponds to about 2,698 C.H. units per sq. ft. per hour. In comparing these two instances it should be remarked that the Babcock boiler was fed with water at 19°C. , while the Lancashire boiler feed had a temperature of 111°C. , which points to the economy of feeding not only boilers but also pans with liquor at or near the boiling point. This may even better be illustrated by an example from actual practice in a works well known to the author. In this particular case, three pots of the form shown in Fig. 141 dealt with 25,000 gallons of liquor per week of 168 hours, evaporating this quantity to 14,000 gallons, so that 11,000 gallons of water were evaporated per week. Each pot possessed a heating surface of 125 sq. ft. The coal used (ordinary furnace slack) per week amounted to 17 tons, and the liquor of sp. heat 0.8 was run to the pots at 20°C. , all the steam produced escaping into the atmosphere. If we assign a heating value to the coal of 6,000 C.H. units it will be found that the fuel was working with an efficiency of 33 per cent., and that there were passing through the metal of the heating surface 1,191 C.H. units per sq. ft. per hour. The system was now improved, one pot of the system was covered in, and the steam led through a heating coil of large diameter placed in the feed tank, so that the pot was fed with liquor at 100°C. It was found by this change that one pot was now sufficient to deal with the 25,000 gallons weekly, and that the fuel consumption to do the same work was reduced from 17 tons to 8.15 tons weekly. This shows an efficiency of 54 per cent., as against the 33 per cent. in the former case. Working this out, the heat transmission amounts to 2,813 C.H. units per sq. ft. per hour.

Turning to the case of the salt-pan mentioned on page 281, it will be found that on making 60 tons of salt weekly the heat transmission is 192 C.H. units per sq. ft. per hour, while during the manufacture of 40 tons per week the transmission amounts to 128 C.H. units. Another instance of low temperature work may be found in the figures upon page 260, Vol. I., relating to the economiser. Here 5,120 sq. ft. of pipe surface exposed to the products of combustion, entering at 399°C. , and leaving at 161°C. , or an average temperature of 280°C. , heated up 23,429 lbs. of water from 16°C. to 111°C. , so that the heat transmission at these temperatures amounted to 435 C.H. units per sq. ft. per hour.

At still lower temperatures than the foregoing, the illustration given on page 58 of this volume, upon the heating of air by the waste gases that have passed the water economiser, may prove interesting and useful. Here 1,920 sq. ft. of pipe surface heated six tons of air per hour from 23°C. to 99°C. by means of waste gases entering the economiser at 214°C. , and leaving at 187°C. , or a mean of 200°C. This works out to 126 C.H. units per sq. ft. per hour. The foregoing cases occurring in actual practice probably represent the bulk of chemical operations, and there is in them sufficient information to enable any engineer to say definitely the heating surface required for almost any kind of work. Certainly one would be much safer in following such precedents than in trusting to rule-of-thumb.

Some evaporators have special appliances fitted to them for the purpose of removing crystals that deposit during the evaporation. There is room for the exercise of much ingenuity in this direction, as almost every substance requires dealing with in a different way. In some plants, mechanical scoops or dredgers remove the "salts," as the deposit of crystals is called, in others they are pumped or run out, while a third system consists in removing them by means of a jet of air or steam after the manner of an injector, though it is much open to doubt whether lifters of this class do really work on the principle of the injector.

Evaporation by means of Steam.—The principles upon which the operations of heating, concentrating and evaporating by the aid of steam depend have already been explained in the first chapter of this volume, when dealing with the Application of Heat and Cold, but it still remains to show how these principles are carried out in practice. We shall find in studying the practical side of the question that the results obtained with different forms of apparatus vary enormously, so that the student should endeavour to find out how these differences come about.

The simple rules given on page 120 may be considered as figures that can easily be attained in practice, though it is quite true that many chemical engineers are satisfied with much less, and yet they fall short of many of the older results that have served as text-books for many years past. Some of the results of evaporation that have been given by experimenters could not in any way be accepted as reliable data for designing plant—not that they should be styled inaccurate, but simply because the conditions under which the experiments were made were not correlative with actual practice. Take, for instance, the experiments of Thomas and Laurens recorded by Peclet, in which an evaporation of six gallons of water per hour per square foot is claimed. That there may be something amiss in the description of this experiment has occurred to others than the author, as may be seen from an extract from a paper which appeared in *The Engineer* for June 13th, 1890, from the pen of Mr. J. G. Hudson, which reads as follows:—

"Earlier in this article—page 291—reference was made to Laurens and Thomas' often-quoted evaporation trials with a tube 138ft. long and 1·36in. external diameter, and to the considerable fall in pressure which must have been needed to cause the steam to flow with the requisite speed through so small a pipe. On looking further into the matter, it seems doubtful whether the quantity of steam corresponding with the work done could have got into the tube at all, under the given conditions, apart from retaining the pressure needed for the high duty recorded. Peclet gives the bore as ·02m. = ·8in., which would require the steam to flow at about 2,300 ft. per second, or faster than it would flow into a vacuum. Even if the stated bore of ·02m., which would make the pipe more than $\frac{1}{2}$ in. thick, be taken as a clerical error, for ·03m., corresponding with the more probable thickness of $\frac{1}{8}$ in. full, the speed would still be about 1,000ft. It would look from this as if the pipe could not have been all in one length, though Peclet refers to it as *un tuyau*."

We have already seen on page 126 that the results obtained with steam heating tubes may vary much, according to the way in which the surface

is built up, and it will be gathered from those remarks that an evaporative effect of six gallons per square foot per hour is quite possible of attainment ; this the author firmly believes, although it must be confessed he has never witnessed it in actual manufacturing work.

It will serve no useful purpose to recapitulate figures that have had their day, and no doubt have been of service in pointing to the goal of perfection ; but some modern experience based upon actual manufacturing results has been placed at our disposal in Mr. Hudson's paper already alluded to, and these have been tabulated, in order to emphasise several points the reader should study fully.

The accompanying table (32) gives some results from Hausbrand's work and from Hudson's paper, together with two experiments by the author upon cast-iron heating surfaces. It will be noted that in all the experiments the water was simply heated to 100° C., no evaporation taking place. The first four experiments A—D inclusive are taken from Hausbrand's experience, and the results show that the simple rule (page 120) may safely be taken for designing, so far as heating water is concerned, when all the circumstances of the case are duly considered, but we must not ignore the six last results of the Table F—L inclusive, yielding as they do such small numbers when compared with the first five experiments.

TABLE 32.

SHOWING SOME RESULTS OF HEATING BY STEAM.

	Heating Surface Sq. ft.	Steam °C.	Liquor		Gallons per hour.	Gallons per hour per sq. ft.	Nature of heating surface.
			In	Out			
			°C.	°C.			
A	120	140°	68°	100°	4,790	40·0	Copper
B	48	120°	52°	100°	1,232	25·6	"
C	13	140°	13°	100°	320	24·5	"
D	66	115°	15°	100°	1,324	20·0	"
E	37	120°	14°	100°	500	13·6	"
F	500	118°	49°	100°	4,200	8·4	Brass
G	212	98°	28°	48°	1,530	7·4	"
H	425	116°	29°	104°	1,550	3·6	"
I	34	122°	10°	100°	108	3·0	Cast Iron
K	1,800	111°	29°	100°	3,600	2·0	Brass
L	384	100°	16°	100°	193	0·5	Cast Iron

The low results are not due to the nature of the heating surface, as the conducting powers of brass and copper do not vary appreciably, and we find that in experiment H a square foot of heating surface of thin brass, heated but 20 per cent. more water than a square foot of thick cast-iron, in Experiment I. In the first place, the influence of the steam temperature must not be overlooked; this is set out in Experiments A and B. The influence of the temperature of the feed is shown in Experiments A and C, but what

are the conditions that have brought down the quantity heated from 25.6 gallons in B to 7.4 gallons in G?

The liquor heated in Experiment B was brewer's mash; that in G was water, the vessel in the former case being a double-bottom copper pan, while in the latter it consisted of a multi-tubular heater, with the steam in the tubes and the water surrounding them. With tubular heaters for water, using steam at atmospheric pressure (100° C.) as the heating medium, Hudson recommends 0.3 square foot of heating surface for each gallon passed through per hour, a figure that, judging from the tables, is likely to cover every contingency. Some experiments made by the author several years ago furnished the figures shown in Table 33. They were obtained from a heater with large steam capacity and small liquor space, the liquid heated being water, and the heating surface thin steel tubing.

TABLE 33.

HEATING WATER WITH SATURATED STEAM AT VARIOUS TEMPERATURES.

(Tubular Heater, tubes 1½ diameter).

	Steam °C.	Liquor °C.		Gallons per hour.	Gallons per sq. ft. per hour.	Remarks.
		Com- mence.	Finish			
<i>A</i>	141°	10°	100°	132	6.0	Heating surface of thin steel. 22 sq. ft.
<i>B</i>	129°	10°	100°	110	5.0	
<i>C</i>	124°	10°	100°	94	4.3	
<i>D</i>	106°	10°	100°	66	3.0	

From the two foregoing tables (32 and 33) it will be seen that ordinary tubular heaters cannot be depended upon to heat up the twenty gallons of water per hour per square foot of heating surface mentioned on page 120 as our standard. Something more efficient must be provided whenever that ratio is desired, but that twenty gallons of water can actually be heated from 13° C. to 100° C. per square foot of the heating surface of a double-bottom pan may be seen by reference to Table 32.

The next table (34) gives some results of actual operations on the large scale, after Hudson, from and at 100° C. It will be seen that unless the temperature of the steam reaches 120° C., there is no certainty that the two gallons will be evaporated per square foot per hour. Some very bad examples of inefficiency in actual manufacturing processes may easily be cited in connection with evaporation by steam. In a double-bottom copper evaporating pan, possessing a heating surface of 50 sq. ft., to which the author was once called in, the evaporation amounted to only thirty gallons per hour, with steam at the boiler of 140° C. (38 lbs.). As this did not satisfy the proprietor, a 2-in. coil, possessing a heating surface of 50 sq. ft., was added, and as this addition did not materially increase the output a thorough investigation was deemed necessary. It was at this stage of the proceedings

that the author was called in, and the reason why such a poor result was being obtained was found to be that the steam supply pipe was not nearly large enough to bring in the steam actually required for the evaporation. By increasing the diameter of the steam supply, and putting the steam into the jacket in several places, providing also for the due escape of air and condensed water, the evaporation was raised to 160 gallons per hour, without having to use the coil. The importance of a good steam supply is also to be seen from one of the experiments quoted by Hudson in the paper already alluded to. He states that in a tubular clarifier containing 38 brass heating tubes, with a total surface of 166 sq. ft., 360 gallons of water were evaporated per hour, or 2.16 gallons per sq. ft. per hour. The steam was supplied from the main at a pressure of from 66 lbs. to 70 lbs., through a pipe 2 in. in diameter and about 20 ft. long. The steam pressure in the tubes was nearly

TABLE 34.
SHOWING SOME RESULTS OF EVAPORATING BY STEAM.
(Temperature of Liquor, 100° C.)

	Heating Surface. Sq. ft.	Steam °C.		Gallons evaporated per hour.	Gallons per sq. ft. per hour.	Remarks.
		Inlet.	Outlet			
A	200	139°	—	925	4.60	E copper heating surface, the remainder brass tubes.
B	200	131°	—	702	3.50	
C	165	134°	—	554	3.30	
D	66	120°	—	185	2.80	
E	37	121°	—	86	2.30	L is the result from a Wetzel rotary concentrator.
F	166	121°	—	360	2.10	
G	200	115°	—	360	1.80	E copper double bottom open evaporator
H	175	118°	113°	263	1.50	
I	175	115°	—	236	1.35	
K	175	116°	111°	202	1.15	
L	144	107°	—	121	0.84	

constant, and averaged 15 lbs. The 2-in. pipe was now replaced by one 4 ins. in diameter, when it was found that the evaporation rose to 554 gallons per hour, or 3.34 gallons per sq. ft. per hour, the steam pressure averaging 30 lbs. in the heating tubes. There are many cases, such as the one just recorded. The author could now point to one work wherein 9,000 gallons of water are evaporated per week of 74 hours in a pan with 300 sq. ft. of heating surface, or 0.4 gallon per sq. ft. of heating surface per hour, and the owners are quite satisfied with its performance. The question of the supply of steam through pipes at various pressures has already been dealt with under the head of Steam, on page 292, Vol. I., while Table 91, on page 295 of that volume, will enable most problems to be approximately solved, without the use of any intricate calculations.

The operation of injecting air into the liquid that is undergoing evaporation for the purpose of increasing the efficiency of the steam has been a

favourite subject with many inventors. When the liquid is in active ebullition, the injection of air does not seem to have much effect, but when evaporation takes place, at temperatures below the boiling point, there is no doubt but that the operation is accelerated, though, of course, the escaping air carries away much heat with it. Hudson carried out some interesting experiments upon the injection of air during evaporation, the results of which have been embodied in the following table.

TABLE 35.

SHOWING THE EFFECT OF THE INJECTION OF AIR DURING EVAPORATION.

	Heating surface. Sq. ft.	Temp. of the steam. ° C.	Temp. of the liquid. ° C.	Gallons per hour.	Air injected. Cu. ft. per hour.	Gallons evapo- rated per sq. ft. per hour.	Remarks.
A	175	115°	—	236	Nil.	1·35	Without air
B	175	113°	—	197	6300	1·12	With air
C	58	120°	—	126	8280	2·16	" "
D	58	—	76°	16	Nil	0·27	Without air
E	58	—	76°	26	Nil	0·45	" "
F	58	—	75°	42	8280	0·72	With air

From the foregoing table it will be seen from Experiments A and B that the injection of 6,300 cb. ft. of air per hour actually lowered the rate of evaporation, but on increasing the temperature of the steam from 115° C. to 120° C. the evaporation was improved from 1·35 gallons per sq. ft. per hour to 2·16 gallons. The difference in the results, with and without air, is more marked when evaporation takes place well below the boiling point of the liquid, and this is shown by the experiments D, E and F of the table. In Experiment D no air was employed, and the steam was so regulated that the temperature of the liquid was kept at 76° C., with the result that only 0·27 gallon per sq. ft. was evaporated. In the next experiment no air was employed, the liquid being agitated so as to present fresh surfaces to the pipes. This operation improved matters, bringing up the evaporation from 0·27 gallon to 0·45 gallon per sq. ft. per hour, but when 8,280 cb. ft. of air were injected per hour the evaporation rose to 0·72 gallon. Thus it would seem that the injection of air is useful in its way when the liquid is not in actual ebullition, and there is no doubt that it acts partly by agitating the liquor mechanically and partly by becoming saturated with aqueous vapour, or nearly so, thus carrying off additional moisture. Hudson's remarks upon the foregoing trials are given in the following words:—

"During the trials with air it was noticed that much more steam was used, though, except in the low temperature trials, less work was done, the extra heat being evidently carried away by the air and wasted. In the

low temperature trials, where there was no ebullition, the mechanical agitation by the air proved useful in increasing the duty, though wasteful of heat." In all problems of this character, it must be remembered that the cost of the fuel is only one of many items that go to form the total cost of production, and if the expenditure of a little excess fuel will bring the volume from 16 gallons per hour to 42 gallons per hour, it is not unlikely that the financial position will be improved.

It is not necessary to describe or illustrate the ordinary open top-jacketed pan, or the many various forms of coil heated pans of old pattern, as in most cases they have to be specially designed for the work in hand, but it is quite necessary to call attention to several points that must be well considered in designing. In the first place, the air that is present in all steam must be allowed to escape. The quantity present in steam is generally small, but if not allowed to get away readily it must accumulate; there is every probability that many instances of bad evaporative efficiency may be traced to this cause. Then, again, the condensed water must be continuously removed, as when the interior of a coil is filled, or even thickly lined with condensed water, the evaporative effect is considerably neutralised. Steam traps are not favourites with the workman who has the control of steam evaporating installations. He usually prefers a steam cock so that he may visually inspect the quality of the escaping liquid from the end of the coil. For this practice, there is much to be said, as the majority of patterns of steam traps will not do what is expected from them. If steam heating elements were made in shorter lengths, and after the pattern of the familiar grid-iron, there would be fewer complaints as to inefficiency, but to construct heating coils of hundreds of feet of pipe of small diameter in one length is only to court inefficiency.

Attention to all the foregoing points has produced an evaporator which stands in the van of this class of chemical apparatus. It is the vertical emulseur-evaporator of Paul Kestner, of Lille, shown in Fig. 143.

This evaporator occupies an extremely small ground space, and as the steam is delivered above the roof, it possesses special advantages in crowded situations. The manner in which it is operated, and the principles upon which the successful working depends, may be easily understood by careful attention to the details shown in the illustration.

The evaporator consists of a vertical tube either of wrought-iron or of cast-iron, according to the working steam pressure employed, and within this tube are placed several tubes of smaller diameter, through which the liquid, undergoing evaporation, finds its way. The peculiarity of this evaporator is that the concentrated liquid is delivered from the apparatus at a higher level than that of the inward feed of weak liquor, and this is owing to the principle of the "emulseur" or the air-lift having been applied to the operation. In the vertical tubes, the liquid occupies the smaller, while the steam is in the casing around them, entering at *e*, the air and condensed water being removed at *f*, where the casing is connected with a steam trap. The liquid to be evaporated enters the chamber *g*, and being cut off from the steam casing by the tube plate, rises in the tubes *h*, where,

being highly heated by the tube surface, it forms an emulsion of steam and liquid, which rises in the tubes to a level corresponding to the pressure exerted by the column of weak and colder liquid. In this state, the emulsion enters the separator *s*, wherein the liquid falls away from the vapour, and finds its way into the strong liquor tank *t*, while the vapour leaves the separator by the pipe *p*, and is carried through the roof of the building.

It is not necessary to place the weak liquor tank *w* at the same level as the strong liquor tank *t*, as shown in the illustration; it may be much below it, but in any other position than shown in Fig. 143 the conditions must be very fully considered and allowed for. There are several forms of this evaporator in the market, but the working principle is the same in all. The various modifications are due to the conditions under which the evaporator is required to work, such as the strength in soluble matters of the liquid, its viscosity, or whether salts or incrustations are likely to be deposited during the concentration. In the case of the deposition of salts, the chamber *g* is enlarged so as to contain them, a downward current is maintained in a portion of the liquor tubes, and the chamber is provided with means for extracting the salts regularly in order to avoid stoppage. There is also an arrangement for washing out the evaporator with weak liquor before the apparatus is stopped, and this operation is particularly necessary when liquors are evaporated to crystallising strength, as otherwise, upon cooling down,

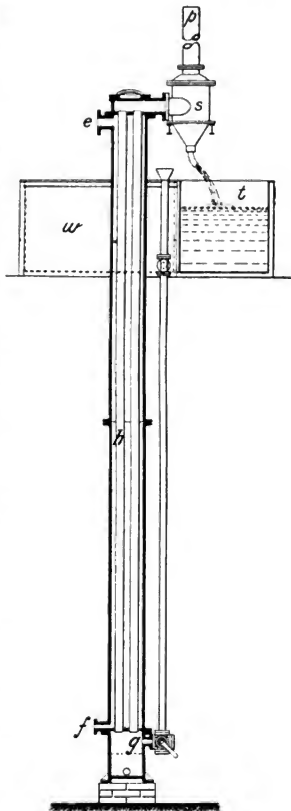


FIG. 143.—
KESTNER'S EMULSEUR-EVAPORATOR.

the tubes might become filled with a solid mass of crystals, which would be difficult to remove. The working of this evaporator is, of course,

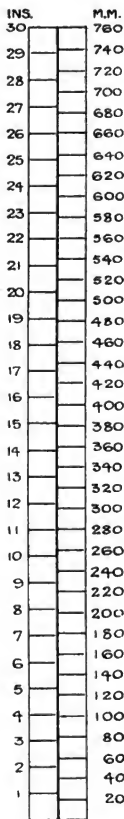


FIG. 144.—BAROMETRIC SCALES COMPARED.

continuous. The weak liquor may be fed in slowly to ensure a flow of fully concentrated liquid at the outflow, or, the liquor may be fed in more quickly and the concentration effected in stages as may be found convenient. In the first method, as when a liquid of 10° Tw. is concentrated to 60° Tw., the steam supply must be carefully regulated by means of a reducing valve, when the working will be found extremely regular. This is not so important when the concentration is effected in stages, as the increased volume of outflow is not affected in so great a degree by small changes in the steam pressure.

Evaporation under Diminished Pressure.—When the concentration of liquids is carried on under a surface pressure of less than that of the atmosphere, it is by general consent styled evaporating in a vacuum. This description is not strictly correct, as a vacuum is never obtained, but of a total possible of 30 inches of mercury, or 760 mm., a good installation will succeed in providing 27 inches, or even 28 inches. In designing or in making our calculations it would be safer to reckon on 26 inches only. It must clearly be understood at the outset what this nomenclature means, as otherwise some ambiguity is likely to arise in following what takes place in the process. A vacuum of 26 inches of mercury signifies a depression of 26 inches in the mercury column from the ordinary atmospheric pressure, but when we speak of 26 inches of mercury, absolute pressure, it is understood to mean that particular height of mercury column standing above a Torricellian vacuum. If we then consider the normal atmospheric pressure to be 30 inches of mercury a vacuum of 26 inches will mean 4 inches of mercury pressure, absolute. This description also holds good whenever the metric system of measurement is employed, 760 mm. being considered as equivalent to one atmosphere, or 30 inches, which, though not strictly correct, is near enough for all practical purposes. In order to be able to compare pressures readily computed on either systems, the accompanying scale will be found convenient (Fig. 144).

The advantages of evaporation under diminished pressures are numerous, some of the points being briefly stated as follows:—Steam at the ordinary

atmospheric pressure, viz., at 100°C. , may be economically employed, after it has been fully utilised for the production of power. As may be seen on page 250, Vol. I., the boiling point of water at 27 inches of mercury vacuum is 45.5°C. (114°F.), so that, under these conditions, there is a greater temperature difference between the heating medium and the liquor to be evaporated than when steam of 120°C. is employed under the ordinary atmospheric pressure. The state of things thus brought about gives us another advantage over ordinary methods. In concentrating solutions of many organic substances, decomposition, or, at least, deterioration would be brought about by a high temperature, sugar would be "inverted," and dye-wood extracts, malt extracts, etc., would be rendered unsaleable if they were attempted to be worked with high pressure steam, but, under a reduced pressure, the low boiling point conduces to economy and allows of a marketable article being turned out. This lowering of the temperature of ebullition is also of use in another direction. In preparing saline solutions for crystallising, they are usually allowed to "settle" and partially cool, before being run to the crystallisers. This preliminary cooling is quite as important as the settling, and it occupies time and space. Take, for instance, the preparation of Epsom salts, which are usually run to the crystallisers at 50°C. If the solution is evaporated in the ordinary way, it will leave the pans at 100°C. , or slightly above, while, if evaporated under a vacuum of 27 inches of mercury the solution leaves the pan at 46°C. , and may be run direct to the crystallising vessels. The table already referred to (Page 250, Vol. I.) shows that under a vacuum of 27 inches the total heat of the steam is 620 C.H. units, the latent heat 575 C.H. units, while, under these conditions, one pound of water produces 190 cb. ft. of steam, or, let us call it vapour, against 27 cb. ft. produced from the same weight of water, under the ordinary atmospheric pressure.

An idea is widely prevalent that evaporation under diminished pressure is more economical than evaporation under the normal pressure of the air, but a little consideration will show that this is not the case, unless waste steam can be cheaply utilised. The quantity of steam required for heating will be practically the same in each case, while, in most other instances, the low pressure system will lose more heat than the other, by reason of the radiating surfaces being more extensive. The advantages of the system lie principally in the utilisation of low pressure steam, which could not be well utilised for other purposes.

Evaporation under reduced pressure must naturally be carried on in closed vessels, closed in so far that the effect of the surrounding atmospheric pressure is excluded, the diminished pressure being obtained by the rapid condensation of the vapour, and the help of an "air-pump," which draws away the permanent gases coming from the solution, from leaky joints, and from the large volume of condensing water required for the operation.

The illustration shown by Fig. 145 will enable the operation of working under diminished pressure to be readily explained. The vacuum pan is seated upon the top floor of the building, and the vapour arising from the pan is first passed into the "save-all," and then descends the vapour pipe into the

jet-condenser placed upon the ground floor of the building. The pan, which is of multi-tubular construction, in this instance, allows the liquid undergoing evaporation to pass through the small tubes, usually of brass or copper, but which of necessity must be suited to the character of the liquid undergoing concentration. The heating steam occupies the space around and between the collection of small tubes.

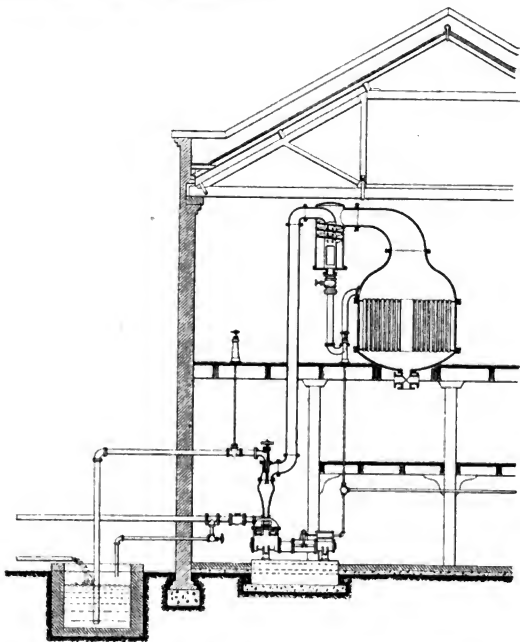


FIG. 145.—COMPLETE INSTALLATION FOR EVAPORATION UNDER DIMINISHED PRESSURE.

The vapour leaving the pan enters the save-all wherein all floating particles froth, and projected liquid is deposited and returned to the pan through the syphon pipe. Were this pipe not trapped, there would be a tendency for the vapour, etc., to be drawn direct into the save-all from the pan, and from thence to the condenser, thus causing a loss of valuable

material. The vapour at last passes into the jet-condenser, where it meets with a sufficient current of cold water to cause its complete condensation. There are many forms of condensers and pumps, but the pattern shown by Fig. 150 will be sufficient to enable the reader to arrive at a full understanding of the process. A complete installation then consists of the pan with all its fittings, the save-all, the condenser and water supply, and the air-pump, or, as it is sometimes called, the vacuum pump. We may now consider each part separately.

The pan itself, so far as the heating arrangements are concerned, needs but little description, as sufficient information has already been given in the chapter dealing with the Application of Heat and Cold to enable the principles of evaporation to be thoroughly grasped, and earlier in this chapter the practical application of those principles has been dealt with. But there are many other points to consider than the heating arrangements, and upon them the form and construction of the pan must depend.

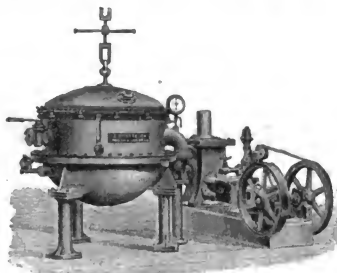


FIG. 146.—ORDINARY VACUUM PAN.
(By Messrs. George Scott and Son, of London.)

The ordinary vacuum pan, as employed for the manufacture of preserves, dye-wood and tannin extracts, and for the preparation of malt-extracts and pharmaceutical preparations on the large scale, is shown in Fig. 146.

In this form the cover is made to lift off for the purpose of removing the contents, and for enabling the inside to be thoroughly cleansed, which is essential, when the pan is used for the concentration of a number of different substances. The heating may be effected by means of a coil, but the usual plan is by the aid of a steam jacket, which leaves the whole of the interior of the pan free from obstruction, the presence of a coil being extremely inconvenient when semi-solid extracts have to be scraped out.

In certain cases coils alone are employed for heating, and, under such conditions, the concentrated material is generally required of such a density only as will run out easily by the outflow pipe and tap. In some instances, such as in the finishing pans for sugars, a number of coils, placed above each

other, are employed, the various coils being shut off one after the other as the evaporation proceeds. Such a pan is shown in Fig. 147.

Vacuum pans are also in use, with coils and jacket combined, for heating purposes, both being employed while the liquid undergoing concentration is thin, the coil being shut off towards the end of the operation. It will thus be seen that the form and construction of the pan of any installation for evaporating under diminished pressure should be adapted to the liquid undergoing treatment, and some previous experience with similar liquors



FIG. 147.—VACUUM PAN WITH A SERIES OF COILS.
(Messrs. Blair, Campbell and Maclean.)

is a *sine qua non*. One detail in connection with a vacuum pan must not be forgotten, viz., a manhole for the purpose of entering the pan for repairs, cleaning and other purposes. Were it not for the fact that the author was once brought into contact with a pan, constructed, too, by a reputable firm of coppersmiths, that afforded no means of entry, save by taking the installation to pieces, he would have deemed this note superfluous.

Multi-tubular heating surfaces are also very largely employed with vacuum pans, especially when salts or solid substances separate from the liquid, and have to be periodically removed. Pans of this kind are generally employed for the concentration of soap-lyes and the recovery of the glycerine

which they contain. The spent-lye contains a large proportion of common salt which separates during the later stages of the concentration, and would choke any apparatus if means were not taken to remove it regularly. A small, self-contained evaporator for this purpose is shown by Fig. 148. It is specially arranged for the saving of space, all the parts being placed on a small platform, the container for the salt being placed underneath.

The arrangement of the pan, together with the subsidiary appliances, is another point that should be well considered. In most installations this is very well done, but the author has seen several plants where no consideration has been given to the economy of a workman's time. A vacuum plant lends itself especially to compactness of design; a straggling plant is evidence of want of knowledge somewhere, and can seldom be worked as economically as in the case of a well arranged installation.

Before leaving the pan, it may be as well to state that it is sometimes assumed that each pound of exhaust steam used in the heating appliance of an ordinary single effect vacuum evaporator will evaporate one pound of water from the liquid undergoing concentration. It is, in fact, actually less than this, as there are many heat losses to be taken into account, but it is a simple figure to remember, and we need not disturb it.

We may now pass to the condenser, and in passing must note the interposition of the save-all (Fig. 145). In concentrating most liquids, especially those of an organic nature, considerable head-room above the liquid is required in the pan. The projection of particles, the formation of froth and foam, and the tendency to "boil over" are some of the little interferences one meets with in the working of a vacuum pan. In most instances, valuable substances would be lost were the foregoing particles, etc., allowed to meet the condensing water, so the save-all is placed in the circuit to enable them to separate from the vapour, and to quietly return to the pan, while the ordinary operations are going on. Practically the save-all is an adaptation of the steam-dryer shown on page 288, Vol. I.

The vapours leaving the save-all should be practically free from particles of the solution occupying the pan, and this vapour requires to be condensed in order that the surface pressure upon the solution may be as low as possible. To the uninitiated, the air-pump of the system appears to be the key-stone,

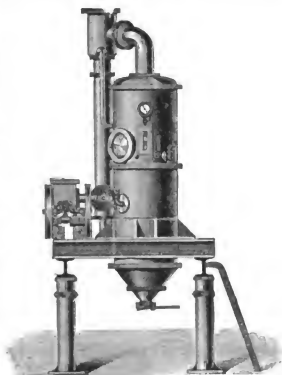


FIG. 148.—SELF-CONTAINED EVAPORATOR.
(Messrs. George Scott and Son, London.)

but, as a matter of fact, this is not so, as in the first instance the perfection of the vacuum depends upon the volume, and therefore the temperature of the condensing water. The air-pump is certainly of importance, as it draws away the permanent gases, already explained, which would ultimately accumulate and increase the pressure on the surface of the liquid, but with hot condensing water it is impossible to secure a vacuum of 28 inches of mercury, which all beginners at vacuum evaporation stipulate for from the maker, and so few provide the conditions necessary for such a state of excellence.

Condensers are of two main kinds :— (a) Jet condensers, in which the vapour comes in contact with the condensing water, and is absorbed by it, and (b) surface condensers, where the vapours are condensed out of contact with the condensing water.

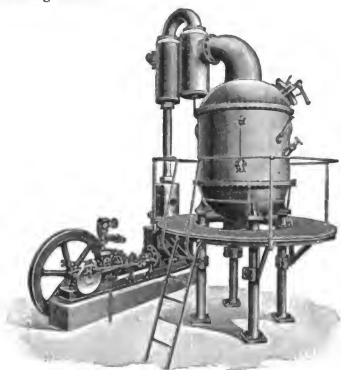


FIG. 149.—A MODERN VACUUM PAN.
(Messrs. Isaac Storey and Sons.)

Jet condensers are of many patterns, according to the idea of the maker, but there is no doubt that the simpler the make the better they will withstand the ordinary tear and wear of a manufacturing establishment. The quality of the condensing water, also, must not be left out of consideration, as distributors with small holes will soon become choked with the mud from dirty water, or the calcareous matter from a hard water. Jet condensers may be further divided into two classes, the first in which the hot water is drawn away by the air pump in conjunction with the permanent gases, while in the second class the hot water runs away by natural gravitation, the air pump being used solely to extract the permanent gas, and the uncondensed vapours, whatever they may be. The air pump used in the first case is called a "wet" air pump, while in the second case it is called a "dry"

pump. Naturally, the construction of the condenser will vary in each of the foregoing instances, and this may be seen in the following illustrations.

The pump shown in the illustration (Fig. 150) may be made to draw the necessary water for condensation from a reservoir, but the point of entry to the condenser should not be above 15 feet from the level of the water in the reservoir, and, in fact, the nearer it is to it, the better. In Fig. 145 the pump is shown delivering the hot water to a cooling tower (see also Fig. 66), and if this tower be of ample capacity the cooling water may be used and re-used continually.

The condenser used with a dry air-pump allows the water to flow away automatically, the pump only being required to draw away the air and permanent gases. It is also called the "fall-tube" condenser, and may be seen in Fig. 151.

The condensing arrangements proper are placed upon the upper portion of the fall-tube, in which, being an open-end pipe, the water stands permanently at a level corresponding to the reduced pressure above it, this level being constantly maintained during the ordinary working of the plant, while the hot water runs away freely. It will thus be seen that the fall-tube must be of greater height than corresponds to 30 inches of mercury pressure. This, from Table 108, page 410, Vol. I. is about 34 feet.

In the "fall-tube" condenser (Fig. 151), the water is admitted above the vapour inlet, so that of

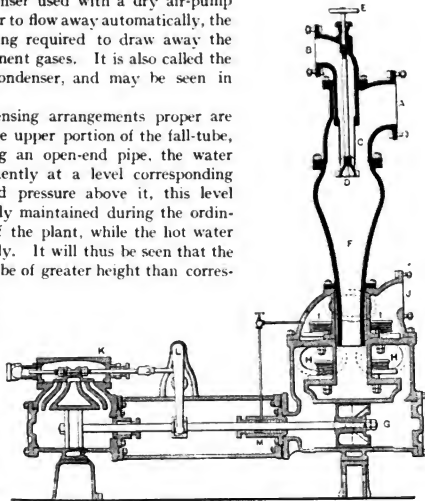


FIG. 150—JET CONDENSER ATTACHED TO WORTHINGTON PUMP.

necessity the condensing water must be pumped to that point, or run from a tank at a superior level. The air pipe, leading to the pump, is also connected to the extreme summit of the condenser.

The water feeding the condenser should be at as low a temperature as possible, as upon its temperature depends the excellence or otherwise of the vacuum. Reference to Table 22, on page 254, will show that the tension of aqueous vapour at 10°C . is $9\cdot165\text{ mm.}$, but at 40°C . it is 55 mm. , a difference of $45\cdot8\text{ mm.}$, or nearly two inches of mercury pressure. This will explain the reason why, in some installations, a better vacuum is

obtained during the winter when water is cold and plentiful, than in the summer, when it is not only warm but often scarce.



FIG. 151.—
FAIL TUBE CONDENSER.

The volume of the condensing water required can be readily calculated with precision, and the dimensions of the pump necessary to take away this water, and to maintain the reduced pressure can also be surely determined beforehand. The volume and weight of the vapour produced may be obtained from Table 84, page 250, Vol. I., from which the dimensions of the vapour pipes connecting the pan with save-all and condenser may be calculated. It is necessary to add here, that vapour pipes are often made too small, especially when the apparatus has been made by an ordinary coppersmith, who, notwithstanding his excellence in that branch of industry, may have but little practical experience of the actual working operations. In calculating the area of the vapour pipes, the velocity of the vapours should not be allowed to exceed 150 feet per second, but it is difficult to persuade the lay mind as to the extreme tenuity of water vapour under a pressure of two inches absolute of mercury. A case in point came before the author several years ago, in which a vacuum pan sold to evaporate 400 gallons of water per hour was fitted with a 5-inch vapour pipe, upon which were two right angle bends. Moreover, the condenser was connected to a deficient water supply, and yet the point upon which the apparatus broke down was never suspected by the makers, as they were continually making other alterations of an expensive nature, which were quite wide of the mark. Four hundred gallons per hour, or 4,000 lbs. of water vapour at the temperature corresponding to 28 inches of mercury vacuum, will occupy a volume of nearly $1\frac{1}{2}$ million cb. ft. (1,413,240), so that 392 cb. ft. would have to be passed per second. This would mean a velocity of 2,880 feet per second, and it is quite certain that the makers could never have reckoned it out, as the theoretical velocity of 50 lbs. steam into a vacuum does not exceed 1,650 feet per second. After replacing the 5-inch pipe by one of 10 inches in diameter, and improving the water supply, the foregoing pan was made to evaporate 150 gallons per hour (with a heating surface of 96 sq. ft.), which appeared to be its limit. Let us now look

at the performance under the altered conditions. One hundred and fifty gallons per hour will mean 147 cb. ft. of vapour per second, and this would pass through a 10-inch pipe with a velocity of 270 feet per second, which is still outside the practical limit already laid down, and the effort that was necessary to force such an amount of work from the pan showed clearly that it was badly proportioned and was being decidedly overworked.

It will at once be evident that neither of the foregoing forms of condenser could be employed where the vapours of valuable liquids are concerned, so that in such cases it is necessary to employ a surface condenser, or one in which the condensed vapours are kept from mixing with the condensing water. The multi-tubular pattern is the one usually employed, and calls for no special comment, except that it appears from the author's experience to be immaterial whether the vapour or the condensing water occupies the tubes, so long as the tube surface and inter-spaces are properly proportioned, and the condenser large enough for the work it is called upon to do.

We have now but to consider the air-pumps used in connection with installations for evaporating under reduced pressure. As already mentioned two varieties are generally employed—the one called a "wet" pump which takes both water and permanent gases from the "jet" condenser, and the other working in conjunction with the "fall-tube" condenser taking the permanent gases only. The wet pump can be approximately proportioned by the volume of water that requires to be pumped, allowing 10 per cent. of this volume in addition for the permanent gases. Generally speaking, the condensing water used varies from 30 times to 40 times the volume of water condensed from the vapour, depending, of course, upon its initial temperature, which should be as low as possible, in order to secure the best results.

A good general rule for air-pump capacity is to allow 5 cb. ft. of piston displacement for every pound of water condensed per minute; this will allow for all contingencies.

A plant put down by Messrs. George Scott and Co., Ltd., to evaporate 40 tons of water per week possessed an air pump, the cylinder of which was 10 inches in diameter, with a stroke of 12 inches, and was run at 40 revolutions per minute. There was then provided :—

$$\frac{(10)^2 \times 0.78 \times 40 \times 12 \times 2}{1728} = 43.3 \text{ cubic feet}$$

which is equal to :—

x

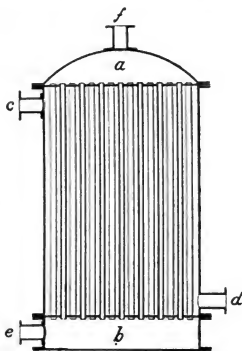


FIG. 152.—TUBULAR CONDENSER.

$$\frac{43.3 \times 168 \times 60}{2240 \times 40} = 4.92 \text{ cb. ft.}$$

of piston displacement per pound of vapour condensed per minute.

During a trial of the foregoing plant, made by the author, using exhaust steam only, 6 lbs. of water were evaporated per minute which, by the before-mentioned rule, should require 30 cb. ft. of piston displacement in the same time, showing that the pump was well above its work, and when steam of slightly higher pressure was employed the 40 tons of water per week was easily evaporated.

By the same rule a pan evaporating 150 gallons of water per hour, such as previously described as an ill-proportioned plant, being at the rate of 25 lbs. per minute, would require an air pump having 125 cb. ft. of piston displacement per minute, and this may be obtained from a pump with a 14-inch air cylinder and 20 inches stroke, running at 40 revolutions per minute. The pump that was actually supplied with the installation in the first instance possessed an 8-inch cylinder, with a 12-inch stroke, and this was afterwards replaced by another having a 10-inch cylinder with a 12-inch stroke, without effecting the guaranteed evaporation.

Evaporation by Multiple Effect. — During the past few years considerable interest has been exhibited in the process of evaporation by multiple effect, in many of the larger chemical industries. In the sugar industry it is quite an old process, but its application to the chemical industry proper is quite of recent introduction. Recent inquiries addressed to the author on this subject show clearly that there are still many manufacturers who have not grasped the leading features of the system, and who do not yet understand the principles upon which the operations are conducted. In brief, the system consists in utilising the heat of the vapour coming from a closed vessel in which water is being evaporated, for the purpose of evaporating a second quantity of water contained in another vessel. When the operation stops here, the evaporator is styled one of "double effect," and if the vapour from the second vessel be made to evaporate water in a third vessel the installation is called one of "triple effect," and so on.

In order that the foregoing principle may be carried out in practice, the last vessel in the series is connected with a condenser and air-pump, which lowers the boiling point so that when the temperature of the vapour has fallen below 100° C. there will be sufficient temperature difference between the heating medium and the liquid to be heated to effect the evaporation in a reasonable time. It has already been shown (page 120) that an evaporation of 2 gallons per hour per sq. ft. of copper heating surface cannot be depended upon unless there be 20° C. of temperature difference between the heating steam and the liquid to be evaporated, and we shall see that similar conditions practically limit the number of vessels that can be used in one series of a multiple effect evaporator. When exhaust steam at 100° C. is employed for heating the first vessel of the series, and the last vessel boils at 37.8° C. under a vacuum of 28 inches of mercury, the difference in temperature between the beginning and the end of the series is 62.2° C., which, if divided between two vessels, is 31° C., between three vessels

20.7° C., between four vessels 15.5° C., while between six vessels the difference between each could only amount to 10.3° C. Of course, it will be seen that if high pressure steam be used the temperatures will be increased, but a limit is found for the direct application of high pressure steam in many instances, on account of its high temperature. In cases where it can be employed satisfactorily, its use is a step in the right direction, but it will be found in practice that high boiling point solutions do not always give off sufficient vapour to keep the second vessel in the series up to the point of maximum duty. It is at this point that one commences to depart from the simplicity of the system, and where the skill in designing comes in.

A great deal of secrecy and mystery is often imported into the subject of multiple effect evaporation by interested parties, so that it is often difficult for the tyro to gain any exact knowledge of the handling of a plant. One of his first thoughts probably is: How is the systematic adjustment of the temperature difference made in each vessel? He need not worry—Nature does the adjustment for him. So long as the initial temperature of the steam remains constant, and the reduced pressure in the last vessel is constant, all other things being equal, the series will adjust itself automatically, and will come into equilibrium again after each disturbance caused by the operations of feeding, running off, etc., when these are carried on intermittently.

One point is very necessary to remember—that the initial power coming from the steam boiler, due attention must be paid to the economical raising of steam. Whatever may be the evaporative efficiency of the steam boiler, each effect of a multiple evaporator will give an approximate duplication—it cannot do more than this. If the steam boiler produces six pounds of steam from each pound of coal burned in the furnace, a single effect may give approximately 6 lbs. of water for each pound of fuel, a double effect 12 lbs., a triple effect 18 lbs., a quadruple effect 24 lbs., while a sextuple effect will roughly yield 36 lbs. of water per pound of fuel burned under the steam boiler. The economy of the multiple effect evaporator is then dependent upon the efficiency of the prime generator, and it is as well that this should be recognised at the outset. In actual practice, 20 per cent. of the heat may be lost by radiation, so that the foregoing figures should be reduced by that amount whenever a critical comparison is needed.

In order to thoroughly understand the working of a multiple effect evaporator it will be necessary to examine a diagrammatic sketch of an installation showing the principal parts. This may be seen in Fig. 153, which illustrates a quadruple effect in sufficient simplicity to enable a full explanation to be made. It will be seen that in each of the four pans A, B, C and D, the vapour space above the liquid is in direct communication with the steam space of the next vessel throughout the series, and this constitutes the principle upon which all such plants are constructed. In the diagram, the first pan A is fed with steam from a receiver containing steam at 12 lbs. gauge pressure, or 118° C. This boils the contents of the first pan A producing vapour at 100° C., which passes out from the vapour space above the liquor in the pan into the steam space of the next pan B, at what is

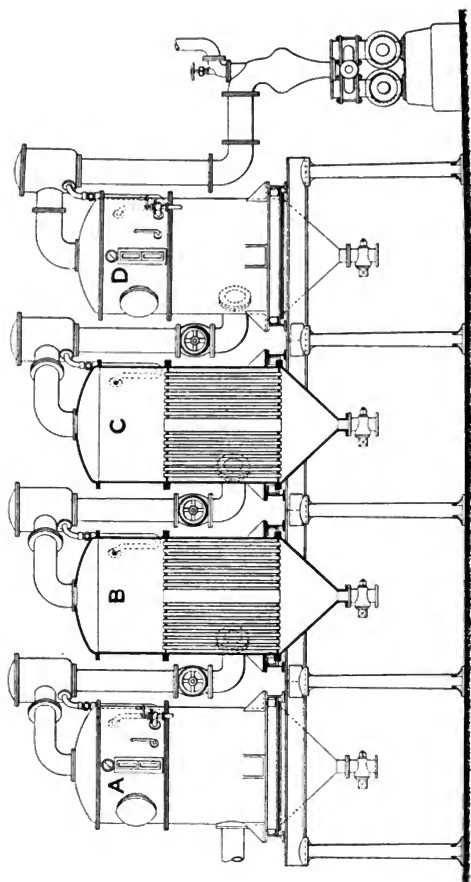


FIG. 153.—A QUADRUPLE-EFFECT VACUUM EVAPORATOR

practically the pressure of the atmosphere. This vapour at 100°C . now heats the liquor contained in the second vessel B, and economical work is rendered possible by the fact that the pressure above the liquid has been reduced by the action of the condenser to 14 inches of mercury vacuum. Under this pressure (which is 16 inches of mercury absolute), water boils at 84°C ., so that there is a temperature difference of 16°C . between the steam and the boiling liquid in the second vessel. In the first vessel the difference was 18°C . The vapour leaving the second vessel at 84°C . now enters the steam space of the third vessel C, the liquor space of which is under a vacuum of 22 inches of mercury (8 inches absolute), causing the liquid to boil at 66°C ., and giving 18°C . as the temperature difference. The vapours leaving the third vessel at 66°C . pass into the steam space of the fourth vessel, the liquor space being under a vacuum of 27 inches of mercury (3 inches of mercury absolute), at which pressure water boils at 45°C ., yielding 21°C . of temperature difference. The vacuum shown close to the pump will probably mark 28 inches of mercury. The vapour leaving the fourth vessel D now passes to the condenser, where it is more or less perfectly condensed according to the perfection of the arrangements at that point of the installation, which have already been described in connection with the single effect vacuum pan. In the diagram, a vacuum is assumed of 27 inches of mercury, which is about the average working amount in practice.

A pan that is rapidly boiling exhibits all the characteristics of the Kestner emulseur evaporator, the liquor tubes being but two inches in diameter, or even less, become filled with an emulsion of liquor and vapour, and consequently this rises in the tubes and is projected above the top tube plate. The liquor must also perforce return to the lower part of the pan, for which purpose pipes of wider diameter are inserted in the series, as if these are not provided the circulation of the liquid will be deficient, and the efficiency of the pan suffers. Each pan is of course provided with a save-all in order to retain liquid particles that might otherwise pass over with the vapour and be lost. It will, of course, be understood that a definite proportion of the vapour passing from vessel to vessel will be condensed according to the amount of evaporation effected in each subsequent vessel, and this condensed vapour must be continuously removed, otherwise the heating surfaces will be restricted. In a single effect vacuum pan, the water condensed from the heating steam is removed under pressure, and this is generally the case in the first vessel of a multiple effect, and sometimes in the second vessel also. In the later vessels of a multiple effect plant, the heating chambers of the pans are under a vacuum, and the condensed water must be extracted from them mechanically, unless a fall tube can be arranged for of a greater height than is likely to be needed for the extreme vacuum the chamber is ever likely to reach. Where the installation is placed upon the second floor of a building there is usually no difficulty in this respect, but where it is necessary to place the pans upon a ground floor the condensed water is extracted from the later vessels by means of a separate pump, which is carefully constructed to pump the water only, while not allowing any of the steam to pass.

The liquor to be concentrated is fed into the first pan A by means of the feed pump, or it may be run in from an overhead tank, and it finds its way from vessel to vessel under the direction of the diminished pressure, so that it finally reaches the last vessel D, from which it flows into a closed receiver placed in such a manner that when full it may be cut out of circuit for emptying without stopping the operation of the pans. This point requires some little consideration in planning a new installation, and with it is connected the problem of drawing samples from each pan while at work. It will be at once recognised that whilst a sample may be drawn from a pan working at a pressure above that of the atmosphere, an ordinary sampling cock similarly placed on a vessel, the pressure in which was less than the atmosphere, would simply admit air and tend to spoil the vacuum, so that some little consideration of the problem how to extract the sample without admitting air is necessary for the successful working of any plant. So far it has been assumed that the liquid follows the vacuum throughout the series of pans, entering at the highest temperature and leaving by the lowest. This is the natural sequence, but it sometimes happens that a flow in the inverse order is required. Whenever such conditions are necessary a pump will be required to force the liquid from pan to pan, or the liquor may be extracted from the pans by means of pumps and delivered into overhead tanks, or, indeed, into tanks on the same level as the pans, according to the degree of vacuum against or with which one has to reckon.

In the caustic soda industry it is usual to divide the concentration of the caustic liquor into two stages. In the first stage, the liquor at 20° Tw., containing ten parts of water to one part of 70 per cent. caustic, is evaporated in a triple effect system until it contains about three parts of water to one part of caustic soda, or to a specific gravity of 1.3 (60° Tw.); this is a concentration to about one-third or 100 volumes to 31. At this point the carbonate and sulphate are insoluble, and crystallise out. The concentration of the clear liquor, less the salts, is then made a second stage by finishing it in a single effect vacuum pan. In an open pan such liquor would finish at 300° F. or 150° C., but under a 28-inch vacuum 100° Tw. (at 15° C.) is reached at 112° C., and, allowing for the difference in temperature necessary between the heating medium and the liquid, say 30° C., we shall have the temperature of steam necessary as 142° C., which is steam of 41 lbs. gauge pressure. By increasing the pressure of the steam to 80 lbs. per sq. in., it is possible to concentrate to 120° Tw. in a vacuum.

In the foregoing example illustrated by the diagram (Fig. 153) the temperatures and pressures may be regarded as normal working figures. They are those actually obtained in working a quadruple plant with water entering the first vessel at boiling point (100° C.). Had the water entered the plant cold, both temperatures and pressures all along the series would have shown different figures, but whatever they had been there would have followed a natural adjustment all along the line, by which a plant of this kind is shorn of many of its apparent complications.

In the trial trip of an installation of quadruple effect, fed with cold water, it was found that 8,780 gallons were evaporated in $10\frac{1}{2}$ hours, and

the fuel consumed in raising steam, including that used for the vacuum pump engine and the water and liquor pumps, amounted to 3,360 lbs., so that the water evaporated per hour was 836 gallons, or 26 lbs. per pound of coal. The figures also show that 0.6 gallon or 6 lbs. of water were evaporated per sq. ft. of heating surface per hour, which are results that may be relied upon in designing.

Double effect pans are now largely employed in the chemical industry with success. They are employed for the concentration of magnesium

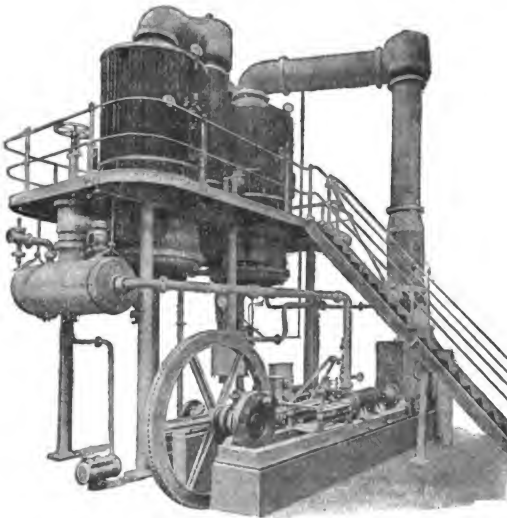


FIG. 154.—DOUBLE-EFFECT VACUUM EVAPORATOR
(By Messrs. Fullerton, Hodgart, and Barclay.)

sulphate solution for the manufacture of Epsom Salts, for the concentration of solutions of silicate of soda, for caustic soda solutions, for glycerine soap lees, for carbonate of soda solutions in the manufacture of soda crystals, for glue solutions, and they have been tried for the manufacture of salt from brine. Fig. 154 exhibits a double effect installation made by Messrs. Fullerton, Hodgart and Barclay, of Paisley.

It may be interesting at this point to refer to a series of observations made during the normal working of a quadruple effect evaporator, of which

full particulars were open to the author. The figures, unless otherwise expressed, refer to a period of 24 hours work.

Heating surface of evaporator, 2,000 square feet.

Feed liquor, 37,200 gallons.

" " Sp. gr. 1.015 at 82° C. (180° F.).

Concentrated liquor, 3,360 gallons.

" " Sp. gr. 1.225 at 71° C. (160° F.).

Distilled water, 31,290 gallons at 89° C. (192° F.).

Hot water from vacuum pumps :—174,000 gallons.

Temperature of injection, 11° C. (52° F.).

" ejection, 43° C. (110° F.).

The weight of water evaporated is represented by the difference in the weight of the concentrated liquid and the feed liquor, thus :—

Weight of feed liquor .. = 37,200 × 10.15 lbs. = 377,580 lbs.

Do. concentrated liquor = 3,360 × 12.25 " = 41,160 "

Pounds of water evaporated .. 336,420 lbs.

The amount of steam required in the apparatus to evaporate this weight of water from the temperature of the feed liquor, 82° C. (180° F.), was found, by actual measurement, to be 5,054 lbs. per hour, which included steam for pumps. The exhaust steam from the pumps connected with evaporators was exhausted into the first evaporating vessel to do useful evaporative work. The evaporative efficiency, expressed in pounds of water evaporated from 100° C. (212° F.), and also from the temperature of the feed liquor, may be fairly ascertained as follows :—

a. Evaporative efficiency from 100° C. (212° F.). Per hour.

Total steam used including pumps = 5,045 lbs.

Less steam required to heat feed liquor
from 82° C. to 100° C. } = 506.5 "

Total steam used to evaporate water from
100° C. } = 4,538.5 lbs.

Water evaporated per hour = $\frac{336,320}{24}$ = 14,013 lbs. and

$\frac{14,013}{4538.5}$ = 3.08 lbs. of water evaporated per lb. of steam condensed in first cylinder.

b. Evaporative efficiency from temperature of feed liquor.

$\frac{14,013}{5,054}$ = 2.772 lbs. of water per pound of steam.

These results are expressed in pounds of water evaporated per pound of steam used, because before we can arrive at the amount of water evaporated *per pound of coal*, it is necessary to know the weight of steam generated by one pound of coal in the steam boilers which supply the evaporator.

It would appear, then, from the foregoing results that the efficiency of any multiple evaporator depends on the temperature of the feed liquor, and that

by a quadruple effect apparatus, slightly over 3 lbs. of water may be evaporated for every pound of steam used, provided the feed liquor be at or very near 100°C .—the boiling point of water. When the temperature falls below this, the efficiency of the apparatus rapidly diminishes also. As before stated, in order to express this efficiency in terms of the coal it is necessary to know how much water one pound of this coal evaporates in the steam boilers, and from this figure the efficiency is easily obtained. Thus, for example, if one pound of coal evaporates $8\frac{1}{2}$ pounds of water in the steam boilers, we have :—

1st— $3.08 \times 8.25 = 25.41$ lbs. of water evaporated from 100°C .

by the multiple evaporator, per pound of coal.

2nd— $2.772 \times 8.25 = 22.87$ pounds of water evaporated from temperature of feed (82°C .) per pound of coal.

The distribution of the heat, therefore, during say one hour's work of a multiple evaporator may be arrived at with tolerable certainty. It is rather humiliating to have to say so, but $8\frac{1}{2}$ pounds of water evaporated to steam in an ordinary steam boiler, per pound of fuel burned in the furnace, is above the usual average. Six pounds of water per pound of fuel is about the general rate of evaporation, and it is better to adopt it in all comparisons; but, in the mill where the foregoing observations were made, the evaporation reached $8\frac{1}{2}$ pounds. The constancy of such results is undoubted, for when once a multiple evaporator is set going under its proper working conditions with respect to the pressures and volumes and temperature of liquid passed through it, the distribution of the heat which enters the apparatus amongst the various liquids flowing from it, and steam condensed in the condenser, are all practically constant. To quote one case may serve to show the nature of this heat distribution for the individual apparatus under consideration, and in a measure for all similar pieces of apparatus. The distribution or analysis of the heat in the liquids leaving a multiple evaporator has an interest beyond the mere theory of the subject, for by this practical men may arrive at a fair understanding as to how, and to what extent they may make multiple evaporators a valuable adjunct to their necessities in connection with its services as a concentrator of liquids. They yield two abundant supplies of hot water—one distilled, the other natural water used for producing the vacuum. These supplies are inseparable from systems of multiple evaporation. In many cases they are extremely valuable to the manufacturer, more especially the distilled water. Both supplies may, for instance, be used for feeding steam boilers, in which case the heat they contain is utilised, and may be considered to have a commercial value.

The distilled water, if used for this purpose alone, has the further recommendation of producing no scale. Its volume also is comparatively large, amounting, in fact, to about 85 per cent. of the volume of the weak liquor concentrated. On the other hand, the volume of the water used for the condenser is, comparatively speaking, very large, and its total consumption for steam raising purposes, excepting in the very largest factories, is quite out of the question. Turning our attention to the distribution of the heat

which enters the evaporator among the liquids which leave it, we may employ the following method, which will answer all practical purposes:—

Heat entering the apparatus:— C.H. units per hour.

$$\text{Weak liquor (feed) } \dots \frac{377,580 \times 0.9 \times 82}{24} = 1,161,021$$

$$\text{Steam (60 lbs. pressure) } 5,054 \times 659 = 3,330,586$$

$$\text{Total} = 4,491,607$$

Heat leaving apparatus:—

$$\text{Concentrated liquor } \dots \frac{41,160 \times 0.6 \times 71}{24} = 73,059$$

$$\text{Distilled water } \dots \frac{31,290 \times 9.7 \times 89}{24} = 1,125,527$$

$$\text{Condenser do. } \dots \frac{174,000 \times 10 \times 32}{24} = 2,320,000$$

$$\text{3,518,586}$$

$$\text{Heat lost by radiation, etc.} = 973,021$$

Expressing these results in simple fashion, we find of the total amount of heat entering the apparatus, there left in the

$$\text{Concentrated liquor} = 1.6\%$$

$$\text{Distilled water} = 25.0\%$$

$$\text{Condenser do.} = 51.6\%$$

$$\text{Lost by radiation} = 21.7\%$$

$$\text{99.9}$$

These percentages show clearly that about 76 per cent. of the heat entering the apparatus is obtained again in an available form as hot water; that one-fourth of the heat entered the apparatus in the feed liquor, and three-fourths as steam. Such calculations inevitably direct the practical man to some of the most telling points in systems of multiple-evaporation, and guide the manufacturer in arriving at a correct conclusion as to their real commercial value to him. They also serve to guide the engineer in adapting multiple evaporation to certain manufactures, so as to obtain the maximum economical effect.

The foregoing percentages must not, however, be confounded with the percentage amount of heat contained in the distilled and condensed waters expressed in terms of the steam actually used in the evaporator. The percentage recovery on this basis is greater than the foregoing. For example, the amount of heat contained in the distilled water from the above apparatus represents 33.7 per cent. of the steam, and that contained in the hot water from the condenser represents 69.6 per cent. of the steam used. It is also evident that in either case these percentages may be taken as a direct measure of the fuel saved by employing either of these sources of hot water for steam raising purposes.

The amount of work done, or in other words the quantity of water evaporated per hour by multiple evaporators, will vary according to their construction, and to the pressures under which they work. The heating surface of the tubes has doubtless the most important bearing on this part of the subject. An apparatus containing 2,000 sq. ft. of heating surface in the form of thin tubes will, under those working conditions laid down as being essential to successful result, evaporate from 6 to 7 lbs. of water per sq. ft. of thin steel-tube surface per hour.

Distillation. — We may now pass on to the subject of distillation proper, wherein the vapour, driven off, condensed and collected is not an adventitious product, but the real object sought. There are many liquids now dealt with by the process of distillation, but they all conform to the same rules, and every problem concerning their manufacture and practical utilisation can be worked out when, in addition to their chemical characters, we know their specific gravities, boiling points, vapour pressures and their specific and latent heats, which may be found in the following table and in Table 12 :—

TABLE 36.
OF BOILING POINTS, SPECIFIC HEATS AND LATENT HEAT.
(See also Table 12, page 113.)

	Specific Gravity.	Boiling Point, °C.	Specific Heat.	Latent Heat.
Acetic acid	1·080	117·3	·522	84·9
Acetone	0·814	56·3	·515	140·0
Aniline	1·036	181·0	·512	93·3
Benzol	0·899	80·4	·407	109·0
Carbon disulphide	1·293	46·2	·239	90·0
Carbon tetra-chloride	1·631	78·1	—	52·0
Chloroform	1·525	60·2	·234	67·0
Ether	0·736	34·9	·527	90·5
Ethyl Alcohol	0·809	78·4	·602	236·0
Glycerine	1·271	280·0*	—	—
Methyl alcohol	0·821	66·8	·591	289·0
Nitric acid	1·522	86·0	·445	115·0
Sulphur chloride†	1·706	144·0	·204	49·4
Sulphuric acid	1·842	327·0	·336	122·0
Water	1·000	100·0	1·000	606·5

* 210°C. at 50 mm. pressure. † S_2Cl_2 .

The simplest installation for the purposes of distillation may be found in the ordinary laboratory still employed for the purpose of obtaining pure water. It consists of the still or boiler in which the vapour is generated and the condenser or worm in which it is condensed, and it will be found in practice that many distilling processes do not require anything more complex than this. The apparatus employed for distilling coal-tar is of this kind, but it can only be used for purposes of rough separation. Each of the fractions from a still of this kind is a complex liquid of many parts, and a much

more complicated apparatus would be necessary in order to separate them into their various constituents.

Stills, or cylinders (or retorts, as they are sometimes called) for the production of nitric acid and of hydrochloric acid are also of this simple character. The retort heated by a naked flame is the counterpart of the laboratory still, while the range of earthenware pipes and the series of Wolff bottles answer to the condensing worm. It will be seen in these examples that both still and condenser may vary within very wide limits in character, material and design, so that the general construction and the arrangements for heating and cooling must have some specific relation to the operations to be conducted within them. In tar stills, the first products come over at or below the boiling point of water, while the last products have a temperature of about 400°C . Then we have the bisulphide of carbon still, wherein even a steam heat is almost too high to be trusted, and the chloride of sulphur still, which is of lead and heated in an oil-bath. Notwithstanding all such differences, they conform to one classification, and however they may be built they consist of the integral parts—the still and condenser.

It is not necessary to go deeply into the details of the methods of heating stills in actual practice, as enough has already been said to enable a correct design to be made. Fire heating has a precedent in the steam boiler, and heating by coils and jackets has also been well considered in treating of evaporation. There are, however, several matters in connection with the subject of distillation that do not always receive prominent attention. First, there is the supply of liquid to the still. There should always be sufficient head-room given, especially with liquids likely to froth, and if the exact quantity of liquid that is being introduced cannot be readily measured in the still itself, there should be an overhead measuring tank from which the exact volume of each charge can be abstracted. Second, every still has a run-off pipe to carry away the residuum, and the construction and placing of this requires a little attention. When the residuum is liquid or semi-liquid, the pipe simply requires keeping away from the hot fire-flues so that it is not burned, or the contents solidified. In tar stills and similar cases, the residuum (pitch) is solid when cold, and means must be taken to keep the run-off pipe hot, but still not so hot as to allow the contents to carbonise. Lastly, stills are not usually worked under pressure, the end of the condenser being open to the atmosphere—or to the vacuum pump when that system of distillation is adopted; nevertheless every *closed* vessel, and every vessel in which the escape of vapour is restricted, should be provided with appliances for ascertaining the extent of the pressure, if there be any, or for relieving it if by any accident or oversight more vapour is being produced than the condenser is capable of dealing with. Many tar stills have exploded from over pressure, and serious loss of life has been the result, the works chemist not always escaping, so that the warning here given is not superfluous. It is the author's opinion that every closed vessel used for the purposes of distillation, solution, or digestion should be provided with a pressure gauge, and with a thermometer or pyrometer of the type shown on page 233, Vol. I., which can be easily read at a distance. Safety valves may answer in some

situations, but they may become veritable explosion traps if they happen to get fast, which they are liable to do with such substances as naphthalin or anthracene.

The condenser receives the vapours coming from the still and abstracts the heat from them with the object of causing their liquefaction. It is a common fault to make condensers too small, with the result that the distillate leaves in a more or less heated state, and this is the cause of much loss when operating on liquids of high volatility.

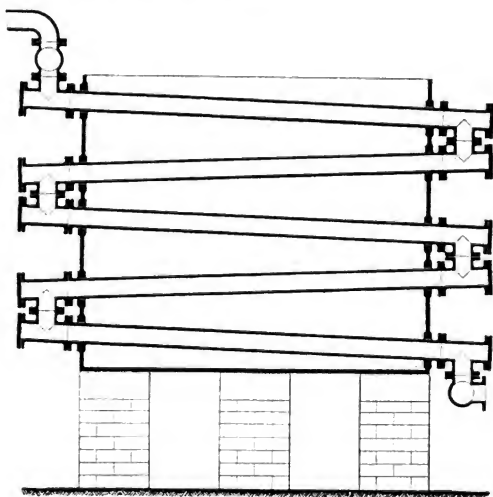


FIG. 155.—TAR-STILL CONDENSER.
(With Outside Joints.)

In designing condensers two distinct types may be adopted, of which all others are but modifications. First, the continuous coil, either of copper, steel tube, or lead pipe, formed of one length of material without joints, and, second, the built up condenser, which may be of many patterns, as the circumstances of the case may direct. The first system is the one usually adopted whenever it can be conveniently applied, as the absence of joints in the cooling water cannot be obtained so easily or so cheaply for the same surface in any other system of construction, at the same time allowing for expansion and contraction, which is a very important matter in intermittent working. Copper coils of any length in one continuous piece can be made

by the process of brazing the ends of several lengths together, and of considerable length in solid drawn metal, and steel tube coils are now made in one length up to 500 ft., which is longer than is advisable for pipes of small diameter. A 2-in. coil of this length is a very powerful cooling appliance if the water supply be properly arranged.

When cast-iron condensing surfaces are required, it is necessary to adopt the second method of construction, but the presence of joints within the cooling tank is always a source of weakness. Methods have been devised for making all the joints outside the tank, and in many cases this is quite satisfactory. If, however, the distillate has a tendency to solidify on cooling, as in the case of naphthalin, such a method could not, of course, be allowed. The two illustrations show particulars of the different systems used in the construction of condensers. Fig. 155 shows the method employed in the best tar works. It will be seen that there are no submerged joints,

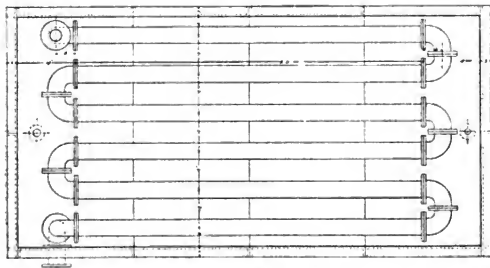


FIG 156.- CAST-IRON PIPE CONDENSER.

the condensing pipes being connected outside the tank, and by taking off the end covers, each individual pipe may be cleaned from end to end.

The next illustration (Fig. 156) exhibits a very common method of building up a cast-iron condenser, but all the joints lie in the condensing water, and if anything happens to those in the lower tier, their repair is exceedingly troublesome; still, however, this method of construction is very largely employed.

The author once designed a condenser of the pattern shown in Fig. 155 to work with a 20-ton tar still making three journeys per week. There were five rows of five pipes each, exposing a condensing surface of 245 sq. ft., and this was found to be only just adequate. A 20-ton tar still will, during the 40 hours it is working, give off vapours which will leave approximately 4,500,000 C.H. units in the condensing water, or in the steam that escapes from the surface of the water in the tank, during the latter part of the distillation, as it is not necessary during this period to keep up the flow of water. This heat transmission is equal to 112,500 C.H. units per hour, or

459 c.h. units per sq. ft. per hour, but the operation is scarcely comparable with the condensation of steam, as, at the commencement of the distillation, the vapours come over at 100° C., while at the finish they exceed the temperature of the melting point of lead.

Taking the foregoing proportions to be sufficient, a 4-ton light oil still would require 50 sq. ft. of condenser surface, but as such a still can be worked much more rapidly in the earlier part of its journey than a tar-still can be worked, it is better to double, or even treble, the condenser surface. A 4-ton light oil still, once worked by the author, was provided with 150 sq. ft. of condenser surface, and the still was made to respond to the duty of the condenser.

Cast-iron coils in several pieces are also largely employed in the tar-distilling industry. They are supplied of very various dimensions, both in bore of pipe and diameter of coil. A coil of 5-in. bore and 5ft. diameter of coil costs about 3s. 6d. per lineal foot, while a coil of 3-in. bore and 3-ft. diameter of coil, will cost about 2s. 6d. per lineal foot.

Systematic Distillation. — It has already been shown that simple distillations, as those of water, tar, naphthalin, etc., require no more complex apparatus than a still or boiler of ample capacity and an efficient condenser supplied with cooling water at a suitable temperature. This is true of all simple distillations, but it will be recognised that the separation of a number of liquids cannot be effected in any apparatus of so simple a character—in fact, the separation of several liquids from each other by the process of distillation is a fine art and requires much study.

When water is the liquid dealt with, we have the steam boiler to guide us as to the capacity of the still, its heating surface, and the best form of construction, while if we choose to employ steam as the heating agent we have the easy rule to remember of two gallons of water evaporated per hour from each sq. ft. of steam heating surface. As to condensing surface, the inverse rule will scarcely hold good, as not only is the distillate required in the liquid form, but in most instances it must leave the condenser within a few degrees from the temperature of the cooling water. Should such volatile liquids as benzol, acetone, chloroform or ether be allowed to leave the condenser in a state of warmth, the manufacturing loss would be enormous. With water—which is of little value—the same restrictions do not apply, except in special instances, but it is well to recognise that in most cases the extent of the condenser surface should be such as to allow the distillate to leave at the temperature of the cooling water. If we refer to page 260, Vol. I., it will be found that a Lancashire boiler working normally evaporates about 470 gallons of water per hour, or nearly 8 gallons per minute; it may readily be made to evaporate 500 gallons per hour, and this is easy to remember, as a good practical figure. In the foregoing boiler, the heating surface was 947 sq. ft., and that of the economiser in which the feed-water was heated 1,024 sq. ft., or, in all, 1,971 sq. ft. If we call it 2,000 sq. ft., such a number will tell us that we need approximately 4 sq. ft. of condensing surface for each gallon of water condensed per hour, and cooled to the temperature of the cooling water. In the experiment described with the tubular heater

on page 291, Vol. I., the water condensed from one sq. ft. of steel tube was one gallon per hour, but this was at 99° C., and would require to be cooled to 10° C. or thereabouts, and we have already seen what extensive surfaces are required as the temperature differences become less and less. From what has been already said in the first chapter, the heating and cooling surfaces may be reckoned out more carefully, though not, perhaps, any more accurately, than in the instance just given, but the author is very partial to figures that have been obtained practically, on the large scale, as they represent actual facts upon which one may rely. In a like manner it will be found that the water required for condensation and cooling will amount to 40 times the weight of the water vapour condensed.

In simple distillations, where liquids other than water are operated upon, the specific heat of the liquid and the latent heat of the vapour are quantities that have to be reckoned with. Sometimes, even in a simple distillation, the product from the condenser is separated into several fractions which by ordinary trade custom have each some specific name. This is the case in the tar distilling industry, where during the distillation of a still of tar, products come over which are termed water, crude naphtha, light-oil, creosote, anthracene oil, etc. Not one of these products is in reality a single substance, but a mixture of many chemical products, some of which are very successfully isolated from their admixture with others by the process of systematic distillation, at which subject we have now arrived, but is one that requires a little further introduction.

Taking as an instance the first tar-still distillate coming over with the water, generally called "crude naphtha," and leaving out of consideration the high boiling "creosote" contained in it, the chief constituents are benzene, toluene and xylene, which boil at 80.4° C., 110° C. and 136° - 140° C. respectively. These hydrocarbons have come over in the one fraction, notwithstanding the differences in their boiling points, so it is rendered clear that something more than a series of simple distillations is necessary to separate even one of them from the other two, to say nothing of the various other compounds accompanying them. It will be as well at this point to inquire why it is that toluene should come over with the benzene, and xylene with both, but for the moment the xylene may be omitted from our consideration, as its introduction will only serve to complicate the explanation.

In most books on Physics the two following laws for the mixture of a vapour with a gas are given in these words :—

(1) The weight of vapour which will enter a given space is the same, whether this space be empty or filled with gas, provided sufficient time be allowed.

(2) When a gas is saturated with vapour, the actual tension of the mixture is the sum of the tensions due to the gas and vapour separately—that is to say, it is equal to the pressure which the gas would exert if it alone occupied the whole space, plus the maximum tension of the vapour for the temperature of the mixture.

Dalton,* when he discovered this law of partial pressures, described it in

* Henry's Life of Dalton. Cavendish Society, p. 35.

these words :—" Let I represent the space occupied by any kind of air of a given temperature and free from moisture, p = the given pressure upon it, f = the force of the vapour from any liquid in that temperature in vacuo ; then the liquid being admitted to the air, an expansion ensues, and the space occupied by the air becomes immediately or in a short time $I + \frac{f}{p-f}$ or $\frac{p}{p-f}$

These laws may not be rigorously exact for a mixture of vapours, but that need not concern us now.

Regnault has shown that when two non-miscible liquids are placed in the vacuous space of a barometer tube the vapour pressure is equal to the sum of the vapour tensions of the two liquids taken separately ; but in the case of two liquids only partially miscible, the vapour pressure is less than the sum of their vapour tensions taken separately, but greater than that of either of them at the same temperature. Liquids that are miscible in all proportions seem to follow no definite law, some possess vapour pressures greater than the sum of their components taken separately, while in others the vapour pressures are less. The facts that have accumulated concerning these matters, and the theories concerning them, are too voluminous and too complicated to allow of their introduction into a work of this character, so the author refers the reader to a work on Fractional Distillation by Prof. Sidney Young, F.R.S.,* which will furnish him with all further information he requires.

It will thus be seen that when a mixture of two liquids such as benzene and toluene is placed in the vacuous space of a barometer tube, both liquids exert their influence by reason of their separate vapour tensions at given temperatures, and that when such a mixture is placed within a still and heated to the temperature of the lower boiling point, more or less as circumstances require, each liquid exerts a definite vapour pressure, and such a mixture of vapours entering a condenser forms what we recognise as the distillate. Water vapour acts as the vapour of a volatile liquid, and the consequences of this may be seen by a perusal of page 278, and in the later portion of this chapter dealing with the distillation of liquids in a current of steam.

When vapours rise from the still in admixture, such as we have seen is necessarily the case, the question arises—How are they to be separated so that one may be kept in the still, while the other finds its way into the condenser ? That this is possible is shown by the fact that a mixture of equal volumes of benzene and toluene can be so well separated in practice that the boiling point of a sample does not vary more than a single degree between the period of the distillation of 5 per cent. and 98 per cent. of the sample. The apparatus for such a purpose may be seen on reference to Fig. 157. The principal parts consist of the still S, the dephlegmating column D, the fractional condenser F, the pro-condenser C, and the condenser and cooler proper W, each of which must now be considered separately.

The Still may be heated by means of a steam jacket, or by means of steam coils placed inside the still. In the case of liquids of high boiling

* London : Macmillan & Co., Ltd, 1903.

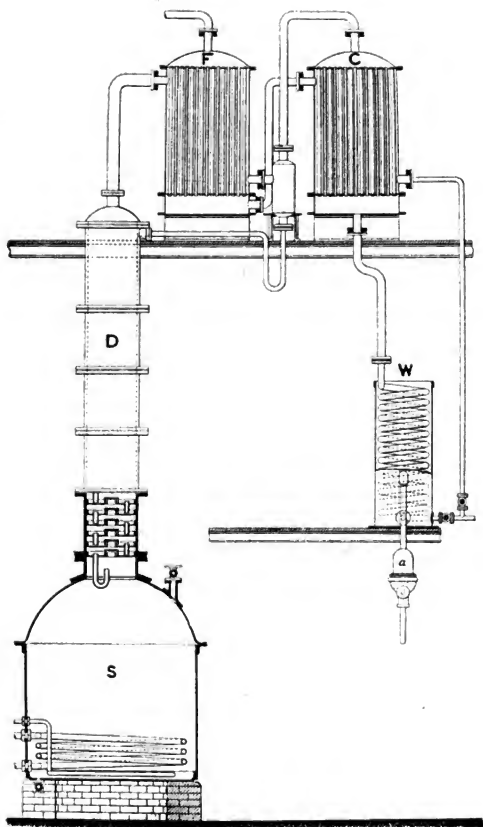


FIG. 157.—COMPLETE APPARATUS FOR SYSTEMATIC DISTILLATION.

points, such as carbolic and cresylic acids, the still must be heated by gas or by an ordinary fire, and this applies to several other substances, even when distilled in a current of steam. The position of the heating coils within the still must be carefully considered beforehand, when the nature of the operation is fully known, as, otherwise, should the liquid be considerably reduced in volume during the distillation, part of the heating surface of the coil is in danger of protruding above the level of the liquid, its heating surface being thus lost, and the vapours would become superheated by the exposed coil, certainly not an advantage. This happens also with steam-jackets when they rise too high round the still.

In many stills of this kind the final stage of the process is effected with open or live steam, and in order that this may enter and be utilised as effectively as possible, a perforated coil of one ring is usually placed at the bottom of the still. A coil of this kind often gives trouble by water or even steam finding its way into the contents of the still when it is not required, by reason of the leaky state of the valve connecting it with the source of supply. This matter has already been referred to on page 301 of Vol. I., to which the reader is again referred. Should maximum work be required from the still, due attention should be paid to the proportion between the diameter and length of the pipe of which the coil is made; this has already been dealt with in a previous chapter, but perhaps the necessity of a good steam trap of ample capacity has not been sufficiently insisted on. Steam traps are nearly always provided of too small a size.

The Dephlegmating Column (D) is the most important portion of an apparatus constructed for the purposes of systematic distillation. It consists of a series of many trays in which the more easily condensed portions of the vapours that arise from the still become deposited. By the method of construction employed, the vapours leaving the still partially condense in the column, and the uncondensed portions are forced to bubble through the liquid lying upon each tray, the effect of which is to condense, in a great measure, the vapours of low vapour tension, and to carry forward those of higher tension. A continual condensation and partial re-evaporation is therefore going on in the column, the condensed portion flowing from tray to tray, and finally finding its way back again into the still as a degraded distillate, from whence it is again re-evaporated by the steam coil within it.

The dimensions of the dephlegmating column cannot well be calculated, except from the results of previous experience, as so much depends upon the heating surface of the coil within the still, the speed at which the distillation is carried on, and the composition required in the final distillate; but the requirements for each special case are well known to the best constructors. The column is built in several ways, some of which may be seen in the accompanying illustration, which is purely diagrammatic, drawn to show the different forms of construction. The top tray shown at *a* exhibits a central vapour pipe covered by a serrated cap. After the still has been at work for some time, the tray, having no other outlet, fills up to the level of the liquor pipe *g*, the liquor flowing down as fast as it is condensed, and so a

constant depth of liquid is kept upon the tray. When this level has been attained, the serrations in the underside edge of the cap *h* become submerged, and any vapour passing from the chamber *b* into *a* is compelled to pass through the layer of liquid, during which passage an interchange of particles takes place, according to the composition and temperature of the liquid and the vapours respectively. This form of tray (Fig. 159) is the least efficient of the forms exhibited, but it has the advantage that the serrations scarcely ever choke up, and an ample current of water occasionally applied will keep the apparatus clean. The second form shown at *b* is a circular cap perforated with small holes, as may be seen in the plan (Fig. 160), the central raised portion where it covers the cap being unperforated. In this form of tray the layer of liquor is determined, as in the previous instance, by the upstand of the liquor pipe, and the perforated

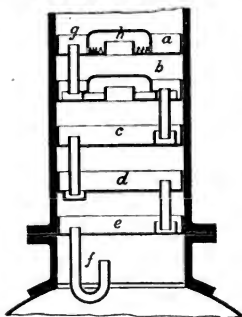


FIG. 158.—
DETAILS OF DEPHLEGMATING COLUMN,

portion of the cap is always submerged while the still is working. The excess of liquor condensed in *a* and *b* finds its way down into the chambers below by the liquor pipe, the lower end of which is sealed in the layer of liquor lying on the trays. If these pipes are not permanently sealed with liquor, the vapours would enter them, and prevent the liquid returning until the whole column was filled with condensed liquid, the pressure in the still increasing while this disturbing process is going on. One inconvenience attending this form of tray is the possibility of the small holes in the cap becoming furred up, and in both the foregoing forms, the liquid always remaining on the trays at the end of the distillation often interferes with the efficiency of the apparatus at the commencement of a new distillation,

until this liquid has been displaced by the new condensate which washes the older liquid back again into the still. In the distillation of crude naphtha, for instance, the final products of the distillation are driven off with open steam, so that at the end of the operation the trays will probably be found filled with water, which lowers the boiling point of the first portions of the distillate of the next charge, until all of it has been vapourised.

The trays shown at *c*, *d* and *e* (Fig. 158) are simply covered with small perforations through which the vapours pass on their way upwards, a layer of condensed liquid covering the tray, the thickness of which is as before regulated by the extent to which the liquor pipe projects above the surface of the tray. If the area of the perforations are properly proportioned to the work the still has to do the liquid will not fall through the perforations while the still is at normal work, a depth of one-quarter of an inch or even more

being easily held up by the pressures of the vapours below, and the only liquid leaving the tray is that flowing down by the dip pipes as they are sometimes called. In the foregoing perforated trays the ends of the dip pipes are sealed in a different manner to those represented by *a* and *b*. When the still has ceased working, any liquid remaining on the trays falls through the perforations, and finally into the still, so that the ends of the pipes would become unsealed. The ends are therefore conducted into small cups, as shown in *c*, *d* and *e*, which remain full of liquid at all times. In some forms, the cups are made to rest upon the tray as shown at *c*, while in others the cup forms a small well as shown at *d*. The construction of the lowermost tray, through which the vapours first enter from the still, is a point worthy of some attention. In this, the outlet for the liquid returning from the column must be safely sealed, as otherwise trouble will be in store for the man who attempts to work the apparatus. If a straight pipe be employed, it should dip nearly to the full depth of the still so as to be sealed at all times, even to the end of the distillation, but as this is not a good form of construction it is usual to bend the pipe upwards as shown at *f*

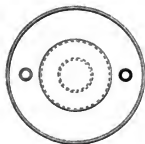


FIG. 159.

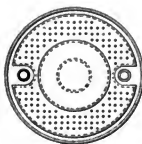


FIG. 160.

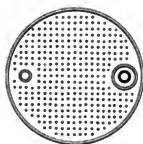


FIG. 161.

in the illustration, which forms a seal equal to almost all eventualities. The action of the dephlegmating column is equal to that of many simple successive distillations. The vapours of relatively small vapour tension are retained within the column, and condensing fall back again into the still, while those of high vapour tension are allowed to pass forward into the condensers. The vapours leaving the top of the column are not, however, homogeneous, their composition as already explained depends upon temperature and the rate of distillation, and the distillate is seldom pure enough for collection—where a pure product is desired—until it has been subjected to the action of the fractional condenser. Thus, a still with dephlegmating column, would serve to extract 90's benzol and toluol from "crude naphtha," but it would not produce "pure" benzol, unless the distillate was produced in so small a quantity as to be financially prohibitive. It must not be forgotten here that the steam (fuel) employed in systematic distillations is several times that required for simple distillation, as all the vapours which are condensed and find their way back into the still have to be converted again into vapour, and this may happen many times in the course of a single distillation. In critical work, such as in making pure benzene or pure toluene, the vapours leaving the dephlegmating column are further treated

in what is called a fractional condenser, wherein they are subjected to a partial cooling and a partial repose.

The Fractional Condenser, shown at F, in Fig. 157, is made in several forms, and is adapted to the requirements imposed by the nature of the substances undergoing treatment. The form shown in the illustration is that employed by the author in 1885 for dealing with the products obtained from coal gas by scrubbing with heavy oils under the influence of refrigeration, and in it the author distilled many thousands of gallons under his own hand. The arrangement differs slightly from most installations one sees in print, by the fact that the vapours leaving the fractional condenser F are made to pass into a pro-condenser C before entering the condenser proper and cooler W. There is a reason for this. The chilling influence of cold water entering the fractional condenser is unmistakable, it being much more beneficial to pass a larger quantity of warm water through it than a smaller quantity of cold water. The fractional condenser is really an adaptation of the tubular condenser shown in Fig. 152. In this instance, the vapours leaving the head of the dephlegmating column pass into the space surrounding the tubes, while water in due proportion enters the base of the condenser and passing upwards through the tubes cools the vapours through the requisite number of degrees. As already mentioned, cold water entering the base of the condenser gives too severe a cooling, and the consequence is that more vapour is condensed than need be. What is required is to keep the whole tube surface at one pre-determined temperature, so far as it is possible to do so, in which case it is also advisable to cover the periphery of the condenser with a very thin non-conducting coating when placed in any situation in which it is likely to be exposed to extremes of temperature. Generally, this is not the case, as the top floor of the distilling room is nearly always warm enough by the time that the condenser water has become heated through.

The vapours, cooled to a certain temperature, leaving the fractional condenser F, find their way into the tube space of the pro-condenser C, wherein they are partially or wholly condensed according to the cooling surface at command. This time the condensing water enters the lower portion of the space surrounding the tubes in C, and leaves by the upper tube, more or less heated, and enters the base of the fractional condenser in that state. In this way there is no chilling influence of cold water to contend with, the temperature of the water being under perfect control as to quality and quantity. As already stated, the fractional condenser may take many forms into which it is not necessary to enter here, as it is sufficient to know the principle upon which such appliances are constructed, and the work they are expected to do.

The Condensers, as already explained when dealing with simple distillations, have a twofold duty to perform—the condensation of the vapour and the cooling of the condensed liquid. The pro-condenser C effects a portion of the condensation, but what proportion of it is not material, so long as a sufficient supply of warm water of a suitable temperature is available for the fractional condenser.

The hot liquid, together with the hot vapour from the pro-condenser, finally pass into the cooling worm W, wherein the condensation is finished, and the cooling of the liquid thoroughly effected, it being most important when dealing with volatile liquids that the distillate should leave the end of the condensing worm at a temperature below that of the atmosphere of the still house, and as near to that of the condensing water as is possible. This means simply, ample condensing surface.

There is, of course, a definite ratio between the heat absorbed during the condensation of a vapour to a temperature slightly less than its boiling point and the heat absorbed during the cooling of that liquid to the temperature of the condensing water, but the figures vary with each liquid and even with the same liquid at varying temperatures, as may be seen by reference to Tables 26 and 36. A knowledge of these figures—latent and specific heats—will enable us to calculate the condensing surface and the cooling surface required to deal with any distillate. The problem resolves itself mainly into one of heat units, with which the student by this time should be familiar, and as heat units are founded on a water basis, the question before us can be best explained by the condensation of steam.

The formulæ and examples already given for the heating of water by steam cannot be followed in the case of condensation and cooling. These operations depend so much upon the actual velocities of the heated vapour and the cooling water over the diaphragm separating them, that without ample margin be allowed one is apt to fall into the common error of having the surfaces too small. Every allowance can, however, be made starting with steam as a basis, and this method will now be followed.

One thousand pounds of steam represent the vapour from 100 gallons of water, and the latent heat of steam at 100°C . being 537 c.h. units, the heat required to be abstracted so that the steam will condense to water at 100°C . will be 537,000 c.h. units. If the cooling water enters at 10°C . and leaves at 60°C ., which are usual average working temperatures, 60 sq. ft. of thin copper surface would be required to convert the steam to water at 100°C . If this work be effected within the space of one hour it amounts to the passage of $\frac{537,000}{60}$, or nearly 9,000 c.h. units per sq. ft. per hour, and if we take the mean temperature difference as 60° , this will mean 150 c.h. units per sq. ft. of cooling surface per hour for each degree of mean temperature difference.

Turning next to the problem of cooling the 100 gallons of water (1,000 lbs.) from 100°C . to 14°C . in a serpentine or cooling worm—with the cooling water entering at 10° and leaving at 60°C . we shall find that

$$1,000 (100 - 14) = 86,000 \text{ c.h. units}$$

require to be abstracted, and practice teaches us that 215 sq. ft. of surface are necessary for the work under the given conditions. This being the case, the number of c.h. units absorbed per hour will be 400, and equivalent to about 72 c.h. units per sq. ft. per hour for each degree of mean temperature difference. Summarising, we find that every pound of steam condensed per hour requires (under the stated conditions) 0.06 sq. ft. of condensing

surface and 0.215 sq. ft. of cooling surface, if the latter be in the shape of the usual serpentine, of which about one-third of the surface will be occupied by the liquid passing through it.

The total number of heat units removed from the steam in the foregoing instance amount to 623,000, so that if the cooling water enters at 10° C. and leaves at 60° C., there will be required:—

$$\frac{537,000 + 86,000}{(60 - 10) 10} = 1,246 \text{ gallons}$$

per hour, or, just over twelve times the volume of the water condensed from the steam. If the water for cooling had been supplied at 10° C., and left at 30° C., the quantity required would have been:—

$$\frac{537,000 + 86,000}{(30 - 10) 10} = 3,115 \text{ gallons per hour.}$$

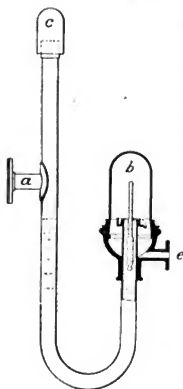


FIG. 162.—
COVERED STILL-WATCHER.

Turning now to benzol for another practical example. A still containing 900 gallons of "crude naphtha" working "nineties benzol" at the rate of 100 gallons per hour, was connected with a copper condenser having 144 sq. ft. of condensing surface. The cooling water supplied to this condenser was 300 gallons per hour, which entered at 10° C. and left at 38° C., showing a heat transmission of 583 C.H. units per sq. ft. per hour, or 24 C.H. units per sq. ft. per hour for each 1° C. of mean temperature difference, proving that the surface of the condenser was ample for this stage of the operation. It should be pointed out, however, that the surface provided was by no means extravagant, as at a later stage of the operation open steam is employed which demands much more surface for its condensation. When distilling light petroleum ether, as is employed in the extraction of oils from seeds (sp. gr. 0.63), or the dry cleaning of garments, etc., it is usual to allow 2 sq. ft. of condensing surface for each gallon distilled per hour, and to make provision for three gallons of condensing water for each gallon of petroleum

ether, when the bulk of it boils at about 71° C.

Two appliances may be mentioned in connection with this subject with which every well ordered still should be supplied—a constant-pressure regulating valve for the steam as shown in Fig. 133, Vol. I., and the still-watcher shown in Fig. 162. Mohr's still-watcher is well known to laboratory students, and an inspection of the illustration will show that the figure is but a modification of it. The liquid running from the worm enters the tube at *a*, and overflows from the shorter limb of the U-tube into a tray surrounding the pipe. This tray is furnished with a lip, which allows the flow to be seen and the hourly volume estimated. The tray is covered

with a glass bell *b* to allow the flow to be observed without bringing the distillate into contact with the atmosphere. It will also be seen from the illustration that the U-tube is of such a diameter as will allow the free floating of a small hydrometer, which may be read without disturbing the bell. The entry limb of the U-tube is shown to be prolonged considerably above the liquor level. The upper end is covered with a cap shown at *c*; it is perforated with a small aperture to allow the pressure of the atmosphere to act upon the surface of the liquor in the tube, and so ensure a steady flow.

Distillation in a Current of Steam.— It has already been mentioned in connection with the operation of the dephlegmating column that live steam is often employed at the end of a distillation, and that in certain forms of tray with which the columns are furnished the water condensed in them is apt to cause disturbances at the commencement of a new operation. We may now see why this is so, and it will furnish an explanation also as to why steam is used at all.

If we take an instance from the working of the still shown by Fig. 157, in which crude naphtha from coal tar was being distilled, it will furnish the student with a guide to what may be expected in ordinary practice when simply "fifty-nineties" benzol and "solvent" naphtha are being worked for. The still was charged with 830 gallons of "crude naphtha," which had previously been well washed with acid, alkali and water. This naphtha after washing was tested by the usual distillation method when it yielded *nil* at 100° C., 18% at 110° C., 37% at 120°, 60% at 140°, and 77% at 170° C. On a second distillation of the first portions, the test showed 19% at 100° C., and 45% at 120° C. Its sp. gr. was 0.912 at 15° C.

After starting, with a small quantity of water on the fractional condenser, the still ran for three hours on "nineties," which was consequently run into the "nineties" tank, at the end of which time the temperature of the contents of the still was 115° C., the heating steam being 130° C. The distillate was then turned into the 50-90's tank for four hours, at the expiration of which the distillate from the worm was running at 0% at 100° C., and 90% at 120° C., the temperature of the heating steam being 144° C., and the contents of the still above 120° C. At this point, the quantity of distillate was a mere trickle, so that open steam was now turned in cautiously and the first portion of the distillate directed into the 50/90's tank until the bulk of it tested 37% at 100° C., and 84% at 120° C. This action of the steam produced again an abundant distillate, though it lowered the temperature of the vapour and brought over more of the lower boiling hydrocarbons than the simple application of coil steam would allow. The open steam was kept going continuously for five hours when naphthalin began to appear in the distillate, the steam was shut off and the operation ended. During the last portion of the distillation, only sufficient water was kept on the fractional condenser to bathe the tubes with steam, and this effectually kept the naphthalin from contaminating the distillate. The solvent naphtha thus obtained showed on distillation *nil* at 120° C., 2% at 130°, 10% at 140°, 75% at 150°, 90% at 160°, 97% at 170°, with no trace of naphthalin in the residue.

From the foregoing run it is seen that the application of live steam will bring over a distillate when it has come to an end with coil steam, and moreover at a lower temperature than when steam is absent from the vapours. In connection with the Porion evaporator (page 278), it has been shown that with saturated vapours at 100°C ., even very hot air admitted to them instantly reduces the temperature to 83°C ., and the same effect is produced when steam at 120°C . is admitted to benzol boiling at 80°C .—the temperature falls below 80°C .

The foregoing effect is also produced with other liquids which do not intermix. If steam is passed into carbon disulphide a mixture of vapours is produced boiling at 42.6°C ., or 4°C . below that of pure carbon disulphide and more than 57°C . lower than the boiling point of water, which is a fact worth remembering. In the recovery of benzol from coal gas, the latter is scrubbed with heavy oil in which the benzol dissolves, but it is scarcely practicable to regain the benzol by a simple distillation. It comes away, however, readily enough when heated to 110°C ., and treated with dry open steam.

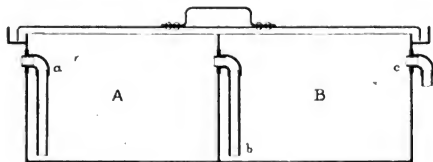


FIG. 163.—SEPARATOR FOR IMMISCIBLE LIQUIDS.

Before leaving this part of the subject, it may be as well to refer to an appliance which allows the water passing over with the condensed vapours, when a current of live steam is employed, to be continuously separated from the immiscible distillate, when both are running together from the condensing worm. This happens in the later stages of crude-naphtha distillation. It would, of course, be easy to allow both to pass into the receiving tank, and as the water would form a layer below the lighter distillate, the former might be allowed to flow away, its passage being regulated or stopped by means of an ordinary tap. The general plan, however, is to use what is called a separator, shown in Fig. 163, in which the water is separated and runs away by one channel, while the lighter liquid is allowed to find its way out by another, the operation proceeding continuously. The separator is really a small cistern of any suitable metal, divided into two compartments A and B, fitted with a cover set in a water lute. When it is used for benzol, the mixture runs into the compartment A, the benzol, being the lighter liquid, passes through the pipe *b* into the compartment B, and from thence through the pipe *c* into the store cisterns. The water, lying as it does at the bottom of the compartment A, finds a ready exit by the pipe *a*, and prevents the escape of any benzol by that channel.

There are many applications of the distillation of liquids in a current of steam, two of which must be mentioned here, as they will serve as a type of most others. They refer to the distillation of glycerine and the distillation of ammonia from crude solutions. In the case of glycerine, the crude article is simply a concentrated solution of soap lees deprived of most of the salt they contain in the dilute state. The solution requires to be distilled in order to separate the glycerine from the organic matters and other contaminating principles contained in the crude solution, but as glycerine does not boil before 280°C . under the normal pressure of the atmosphere, and then only with partial decomposition, the distillation is always performed under diminished pressure. Even then the boiling point is high, being 210°C . at 55 mm. absolute pressure, so that the operation is accelerated by blowing superheated steam into the contents of the still, and under these conditions a distillate appears at about 170°C ., which is condensed and afterwards concentrated under diminished pressure, with high pressure steam.

The refining of glycerine is an exceedingly interesting process, and teaches one much in the way of fractional condensation, for if the operation is not carefully performed there is likely to be a large loss of valuable material, and in the event of this eventuality not occurring, the fractions may be weak and require undue concentration. The *modus operandi* is this :—Crude, 80%, glycerine is charged into a plain cylindrical still, fitted with a perforated coil for the admission of superheated steam. The still is heated with a small fire of coal or coke, and is connected to a condenser and vacuum pump, a fairly extensive fractional condenser intervening. The pressure in the still is diminished to 26 or 28 inches of mercury vacuum by means of the air pump, and as the temperature rises water first appears as a distillate, followed by a mixture of water and glycerine. The steam is superheated to about 260°C ., and the distillation goes on merrily at about 170° to 180°C . Distillates of various degrees of strength are drawn from different positions of the fractional condenser, the arrangement and construction of which are important factors in the success or otherwise of the operation.

This process is scarcely one for the employment of a jet condenser. Under perfect conditions of working it is quite possible to avoid loss of glycerine in the condensing water, but with inattention the losses may be large, so that with such valuable substances as glycerine it is well to rely solely upon the surface condenser, which must be of special pattern to suit the circumstances of the case. One point to be remembered in constructing plant for pure glycerine is—that anhydrous glycerine will take up impurities from almost everything with which it comes in contact at high temperatures. The distillation of pure glycerine is to say the least a highly technical operation, not to be engaged in without ample previous knowledge of distilling operations, and if the fractional condenser be not properly worked, it is more than probable that the financial results will not be satisfactory. There is yet ample room for invention in apparatus for the production of pure glycerine.

We may now pass on to the distillation of solutions of the volatile salts of ammonia in a current of steam; an operation very largely practised at the

present time, especially in the manufacture of liquor ammonia, anhydrous ammonia, and the production of sulphate of ammonia from residual gas liquors. In the good old days when there was but little need for economy, gas water was heated in a cylindrical boiler until the ammonia or ammonia salts were evolved. At first, an open fire was employed for heating, the fixed ammonia being left in the spent water, and was run away to waste. When economies came to be practised, the introduction of lime into the boiler caused such heavy repairs that steam coils were substituted for the open fire with advantage, and finally live steam came to be adopted, which was found to be a very great improvement. In distilling ammoniacal solutions with an open fire, or a closed steam coil, it was necessary to distil over nearly one half of the solution in order to obtain 97 per cent. of the ammonia entering the still, and only one half of this was strong enough for direct use, the second half being usually redistilled to form stronger liquor, before it was directly utilisable.

During 1877, in a work well known to the author, ammoniacal liquors were distilled by a combination of both closed steam coils and live steam. The closed coil was employed to produce "strong liquor," amounting to about one-fifth the volume of the charge, live steam being used afterwards to drive off the residual ammonia, until the liquid in the still contained 0.11 per cent., at which degree it was considered too poor to continue working. The distillate produced by the use of live steam was called "weak liquor," and was redistilled with coil steam.

The "Coffey" still, used long before the above date for the production of strong alcohol, was at this time at work in several ammonia factories, but its employment did not extend, as the apparatus was too complicated for such rough purposes as the distillation of ammonia from gas residuals. The plan now universally adopted is the employment of what is known as the "column still," the author's modification of which may be seen in Fig. 62, on page 125.

The column still was not devised in its present state of completeness at one step. The modifications it has undergone have been brought about by the desire to rectify many of the faults of construction almost inherent in early types of apparatus, and the necessity of producing an appliance that could be placed in charge of unskilled labour. With the earlier stills, many little troubles were found to exist in practice, but one after another they have vanished under the constructor's hand. The presence of tar in the ammonia liquor, the carbonate of lime mud in the spent liquid, the necessity of cooling and condensing the waste gases, the cooling of the spent water, and the suppression of the sulphuretted hydrogen nuisance have been points to which the chemical engineer's attention has been directed.

In working a column still, the liquid containing the ammonia enters the column above the top tray and after forming a layer of definite depth, flows down from tray to tray until it finds its exit in the base of the still, freed from ammonia. Live steam is admitted into the still base, and finds its way upwards from chamber to chamber of the still through each central aperture, forcing its way out through the liquor standing upon each tray, by means of the serrated apertures in the lower edges of the caps covering

the central apertures. The uncondensed steam passing through the liquor carries the bulk of the ammonia with it from tray to tray upwards, and these concentrated vapours escape from the still in company together, the relative amounts of each being determined by the construction of the still and the care with which it is operated.

The more one leaves the broad path of rule-of-thumb, and enters the narrow way of scientific method and economy, the more complex does our apparatus become—it must ever be so, and the need will therefore be seen of placing well drilled superintendents in charge of processes in which the old beaten track is left. It is notorious that nine-tenths of the improvements in chemical methods have been smothered in their infancy by being placed in unskilled hands. Many inventions have arrived too soon, coming to light before those for whose use they were intended had been educated to receive them, or had been able to organise for their reception.

The foregoing remarks apply to column stills perhaps more than to any other chemical appliance known to the author. When they were first introduced into England in 1885, the mishaps with them were ludicrous, but they were nearly always put in charge of an ordinary day labourer—and we need not expect to find much scientific knowledge or engineering skill in a man with wages at eighteen shillings per week. To-day there seems to be no difficulty in working these stills with intelligent labourers, and their use is very extensive.

The construction of column stills must naturally depend upon the kind of work to be done in them, which may be very various. The simplest form is that employed in the distillation of the ammoniacal liquor recovered from blast-furnace gases. This liquor consists mainly of a weak solution of carbonate of ammonia, there being practically no fixed salts of ammonia present, so that a prolonged boiling is sufficient to drive off the whole of the ammonia. In such a case, a still of 15 trays will leave no ammonia in the spent water, and the actual quantity of excess steam required to effect this is so small that solid carbonate of ammonia may appear and condense in the outlet pipe from the still. This was one of the inconveniences which occurred on the introduction of these stills, soon overcome, however, by the employment of excess steam, which though considerably more than theoretically required, was only about one-fourth of that used in the old cylindrical still. A column still of this character, 4 feet in diameter, will deal with 400 gallons of liquor per hour, while a still 6 feet in diameter will treat nearly one thousand gallons per hour. The larger the number of trays in the still, the more completely is the ammonia extracted, and with less steam. A still of this kind is employed in the direct process of manufacturing cyanide of sodium, 13 to 15 trays furnishing dry ammonia gas to the fused mixture of sodium carbonate and charcoal into which the ammonia is forced, the spent liquor being quite free from ammonia.

The ammoniacal liquid sold as "concentrate" for various purposes, for the manufacture of muriate, and for use in the ammonia-soda process, is also produced in a column still, but in this case lime is employed in order to liberate the "fixed" ammonia. This necessitates an alteration in the

form of construction, which is generally carried out in this way :—A chamber containing the milk of lime, fed in continuously by means of an injector, or small pump, is placed midway down the still, as is shown in Fig. 62, page 125. The liquor enters the still at the top, and before it reaches the point where the lime vessel is placed, the whole of the carbonate and sulphide of ammonium have been removed. The solution containing fixed ammonia now enters the lime vessel, mixes with the milk of lime, and forms a calcium salt with the acid, liberating the ammonia, which is driven off by the current of steam, and mixes in the upper part of the still with the vapours from the non-limed liquor. Sufficient steam is admitted into the base of the still to give that excess necessary to keep the whole of the ammonia salts in solution on their passage through the condenser. Crude "concentrate" is usually about 16° Tw., and contains on an average in grammes per litre :—160 grammes of ammonia, 187 grammes of carbonic acid, and 20 grammes of sulphuretted hydrogen. It contains many other impurities, such as ferrocyanides, sulphocyanides and phenol.

A still similar to the foregoing is employed for the manufacture of sulphate of ammonia, and as thus used may be seen in Fig. 62, page 125. Usually, works of this kind are situated on the outskirts of a town, and the spent water from the still is more often than not discharged into the public sewers. As an ordinance prohibits the discharge of heated liquors into these channels, the spent liquid leaving the still is caused to flow through a coil immersed in a vessel called the "economiser," interposed between the feed-water pump and the steam boiler. By this means, the spent liquid is cooled to below 30° C., while the feed-water is heated to about 80° C. An inspection of the illustration will show upon the left hand side a vessel called the heater which utilises the steam coming from the saturator; this steam must be condensed before the sulphuretted hydrogen accompanying it can be satisfactorily absorbed in oxide of iron, and this is effected by using the cold raw gas-liquor as the cooling agent. This enters the heater at 10° C., and leaves at 65° C., at which temperature it enters the topmost tray of the still. The heater shown in the illustration is of special pattern and was devised so that the joints between the steam space and the liquor space should be visible to the eye, as the old form of cast-iron coil (Fig. 156) allowed of undetected leakages and loss.

The column still is now about as perfect as it is possible to make it without unduly complicating its construction, and so rendering it too intricate for an ordinary workman to manage, but still much may be done by the purchaser to secure efficiency. If efficiency is really desired it is useless to cut down the surfaces of the still, and the heating and cooling surfaces of the heater and economiser, until they are all too small to do the work properly. This, however, is what happens very often, on the pretence of cheapness, but if the matter were carefully inquired into, it would soon be found that a small extra expenditure in practically non-destructive metal is better than a continual waste of ammonia and a constant heavy bill for waste steam.

Before leaving the subject of column stills, it may be of interest to notice the principle upon which they work. We have already seen that the

operation carried out in the old cylindrical stills was not economical. To illustrate this, let the student take a litre of a solution containing about 50 grammes of sesqui-carbonate of ammonia, and distil it in a glass retort, to which is attached a good condenser, catching the distillate in fractions of 100 c.c. each.

The solution will probably be found to contain 14 grammes of ammonia, and the various distillates will average about as follows :—

The first	100 c.c.	.....	8.33	grms., or 59.5%
„ second	„ „	.....	3.57	„ „ 25.5 „
„ third	„ „	.....	1.09	„ „ 7.8 „
„ fourth	„ „	.....	0.34	„ „ 2.4 „
„ fifth	„ „	.....	0.17	„ „ 1.2 „
„ sixth	„ „	.....	0.07	„ „ 0.5 „
„ seventh	„ „	.....	0.05	„ „ 0.4 „
„ residue in the flask	....		0.06	„ „ 0.4 „
			13.68	97.7

so that to obtain 96.4 per cent. of the ammonia originally present in the liquor, no less than 50 per cent. of the volume of the liquid would require to be distilled over. It will be seen, moreover, that only the first two fractions are stronger in ammonia than the original liquor, so it is quite evident that this is not an economical method.

From Schlösing and Rolland's researches we know that the strength in ammonia of the vapours disengaged from weak ammoniacal solutions is fifteen times greater than the strength in ammonia of the liquid from which the vapour is generated, and it is the application of this knowledge that has made the column still successful. The steam in its passage upwards through the various layers of liquid lying upon the trays becomes more and more charged with ammonia, so that by the time the vapours escape from the still they will contain about one-third of their weight of solid ammonium carbonate. A column still of twelve trays 4 feet in diameter will, if properly worked, allow more than 270 tons of gas water of 5° Tw. to be passed through it per week, which should produce about 24 tons of sulphate of ammonia, using 57 tons of steam, or the equivalent of 9 tons of coal. When "concentrate" is being produced, much more steam than this is required, in order that the distillate may remain liquid; it is usually proportioned so that the distilled liquid contains about 63 per cent. of water.

The theory of the column still has been clearly explained by M. Sorel in his book, "*La Grande Industrie Chimique Minérale*,"* to which the reader is referred for the mathematical aspect of the problem. Its practical aspect may be mentioned, by saying that a 4 feet still consisting of 13 trays, six above the liming chamber and seven below, when running with ordinary gas water of 5° Tw., generally shows a waste in the exit water from the base of the still of less than 0.001 per cent. Working without lime, the contents of the tray immediately above the liming chamber will contain 0.3 per cent. of ammonia, while, when lime is used, as it almost

* Paris: C. Naud, 31, Rue Racine. 1902.

always is, the contents of the same tray will show at least 0.6 per cent.

Sublimation. — This operation is one that may be considered here, but though it bears some resemblance to the process of distillation, is somewhat distinct from it. In all true distillations, the liquid is first transformed into vapour, and upon withdrawing the latent heat of this vapour, liquefaction follows. Some solid substances—solid at the ordinary temperature of the air—are capable of distillation, in which case they first melt, are then converted into vapour, which liquefies on the application of cold, becoming solid when the temperature has been sufficiently depressed. But there are other solid substances that do not pass through the liquid stage, at least under ordinary conditions, but when heated they become at once vaporious, and condense to a solid when the heat is removed, without passing through the liquid state. This is true sublimation.

Many substances, however, may be both distilled and sublimed. In the case of naphthalin, the distillation process is one of the easiest, provided that due attention be paid to the temperature of the condenser, and the same may be said of sulphur, while the sublimation of each of them seems to depend upon the presence of an inert gas which lowers the pressure under which the condensation is taking place. The two most important manufactures wherein the operation of sublimation is performed are those of carbonate of ammonia and sal ammoniac, the former being a hydrated compound, while the latter is anhydrous chloride of ammonium. It is open to doubt whether either of these operations is, strictly speaking, a true sublimation in the sense just described, as dissociation takes place upon heating and recombination occurs when the vapours are exposed to cooler influences.

The apparatus employed for the purpose of sublimation is simple in the extreme, consisting merely of a pot or other receptacle to contain the substance to be sublimed, while the cover with which the receptacle is furnished acts both as condenser and receiver for the sublimed product. But although the apparatus necessary for this operation is simple, there is considerable latitude allowable in the design and the disposition of a subliming plant, not perhaps in the subliming pot itself, but in the details and accessories leading to and from it, and here the knowledge and foresight of the chemical engineer come in. The raw material has to be prepared for the pots, these require charging and cleaning out, the covers thereof have to be lifted and the cake removed, all of which operations require well thinking out, otherwise the cost of labour will eat a large hole in the profits. Then, again, the application of heat to the raw material is one of the most frequent causes of irregularities in the quantity and the quality of the product; indeed, the author opines he is correct in stating that there is no other operation in the whole of the chemical industries where the selling department is so much in the hands of the workman as in the process of manufacturing chemical products by sublimation. It seems now to be a question of how long this process will continue. The processes of briquetting, of compressing into tablets and tabloids, are now furnishing the market with several articles that were formerly produced solely by sublimation, and there is no doubt that a considerable extension of the practice will follow.

CHAPTER V.

CRYSTALLISATION AND DIALYSIS.

The objects of crystallisation are many. In the early days of chemical manufacturing, it was universally recognised that a crystalline product fairly represented a pure and definite substance which the purchaser could identify, so that there need not be surprise shown now at the preference manifested by the public generally for crystallised products. Custom has kept the crystal in evidence up to now, and there seems no immediate probability of its going out of fashion.

But from a manufacturer's point of view, the operation of crystallisation is most important, as it enables him to separate many substances from each other, which could not otherwise be practically dealt with, thus effecting a purification of some main product, or even enabling some operation to be worked which would not be financially successful without its aid. In the preparation of articles for the market, we have illustrations in the crystallised forms of carbonate of soda. The ordinary form, known as "soda crystals," is the deca-hydrate, and is obtained by crystallising at the normal temperature of the air. Another form of crystallised carbonate of soda is that called by the makers "Concentrated Crystal Soda," which is the hydrated sesquicarbonate, while there is still another variety, the monohydrate, produced at a high temperature. It is rare, however, that the same substance appears in the market in so many states of hydration.

The tendency of substances to leave impurities behind them in what is known as mother-liquor was well known to the earliest manufacturers. Beaumè, in his *Manual of Chemistry*, published in 1786, says :—"If several salts are dissolved in the same water, they are confounded and intimately blended together ; but, on crystallising them, the particles of the same kind assemble, and the crystals of the different salts separate, and are not confounded." Of course, it is well known that crystals containing relatively small quantities of impurities may often be purified by re-crystallisation, but from what the author has seen in many manufacturing processes, it is quite evident that the physical side of the question has not been sufficiently studied by those who have the everyday charge of such operations.

The alum manufacture is one example of the necessity for complete separation of detrimental impurities. In the case of soda crystals, already mentioned, the necessity of absolutely eliminating all foreign matters is not imperative ; indeed, the labour of so doing would add considerably to the cost of manufacture, without adding appreciably to the value of the product.

Soda crystals contain about 21·3 per cent. of alkali (Na_2O), when dried in the old-fashioned way on a drainer placed in a warm room, which is equal to 36·4 per cent. of carbonate of soda. When they are simply lifted from the crystalliser, and immediately passed through a hydro-extractor, and packed into bags, the crystals usually contain 35 per cent. of carbonate, and 63 per cent. of water, the impurities consisting of about 1·75 per cent. of sulphate of soda, and about 0·15 per cent. of common salt. Considering the fact that the operation is one of a first or crude crystallisation only, it will be seen that the separation is exceedingly good and complete. Much depends, however, upon the temperature at which crystallisation takes place, and upon the length of time taken by the operation. If a crystalliser furnishing three tons of soda crystals per journey be examined after the tenth day from filling, supposing the liquor has been made from Leblanc soda-ash, the points, or large crystals, will be found clean and pure, but on examining them again after the periods of fourteen days and twenty-one days, it will be seen that crystals of the deca-hydrated sulphate of soda are growing upon them, having attained a fair size in three weeks, but though the quantity of sulphate of soda so deposited is comparatively small, it is a fact to be reckoned with in the preparation of pure crystals, as we shall see presently. In fact, the presence of sodium sulphate is so general in all manufacturing solutions, and its behaviour so varying and anomalous, that the reader will find it good exercise to study its solubility in connection with other substances likely to be present with it, in solution. Turning again to the alum manufacture, the quantity of impurities allowable in soda crystals as a marketable article would absolutely ruin the sale of alum crystals, especially as the impurities in these latter are likely to differ in kind from the impurities present in soda crystals. In alum manufacture, the *bête noire* is iron in any shape or form, and a preliminary crystallisation is necessary to extract, in the first instance, a fairly pure small crystal from which the ferruginous mother liquors may be more or less completely eliminated. These crystals are again submitted to solution and crystallisation, and form the ordinary alum of commerce. When a still purer form is desired, a third crystallisation is effected, but, a later subsection of this chapter must not be anticipated here.

The student may perhaps infer from what has already been said that it is always easy to separate one or more salts from another by simple crystallisation. Generally speaking, this is by no means the case, although there are many instances where it may be practically effected. In most cases the separation is partial only, one portion crystallising out, while another part remains in the mother liquor, still it is surprising in many instances how much may be done by fractional crystallisation which will often remove an injurious excess of some impurity present in solutions, leaving them in a workable state for other operations. But the separation of many salts from each other by means of crystallisation is often hindered by the formation of double-salts, a class of crystalline formations deserving of more attention than is usually given to them by practical men. To take as an example the double sulphate of soda and ammonia. Several processes have been devised

—perhaps it would be better to say imagined—in which sulphate of soda has been urged to act upon a salt of ammonia, with the production of the corresponding salt of soda, sulphate of ammonia being the secondary product. In many cases, partial decomposition is in fact brought about, but the two sulphates are practically inseparable by ordinary crystallisation, as when such a solution is allowed to crystallise in the cold, from a warm solution, a definite crystalline double sulphate is the result, and when the liquid is evaporated by heat the double sulphate is also deposited as a granular crystalline salt, and a further re-crystallisation of this deposit will only yield the double salt again. There is a further example in the crystals produced in the treatment of galvaniser's flux. The soluble ammonia salts are washed out, crystallised and sold at a low price as muriate of ammonia, but this is not an accurate description of the crystal, as it is in reality a double chloride of ammonium and zinc. Likewise, when ferrous iron is an impurity in sulphate of copper liquors it is exceedingly difficult to eliminate the iron from the sulphate of copper crystals, on account of the tendency to form a double sulphate. At one time a large trade was done in "agricultural sulphate of copper," which was, in most cases, a double sulphate of iron and copper.

Crystals may be anhydrous, such as lead nitrate, common salt, or sodium nitrate, or hydrated as in the case of ferrous sulphate, copper sulphate, or carbonate of soda, and further, they may be deliquescent, stable, or efflorescent. This being the case, it is quite evident that the same treatment will not do for them all. Common salt might be dried at a high temperature, and still be fit for the market, but if ferrous sulphate or sodium carbonate were similarly treated a heavy loss would fall on the manufacturer unless this special drying formed part of his contract. Deliquescent crystals, like calcium chloride, copper nitrate, or magnesium chloride require careful and special handling, and this is also the case in those unstable combinations, of which the carbonates of ammonia are types.

No general code can be formulated in dealing with this subject, either for the production of definite crystals, the amount of their hydration, or the strength of the solutions from which they are most economically formed. Each crystalline product is a study in itself, though certain well defined principles may serve as a guide and lead to a more careful study of each individual problem. In this connection, the author would refer to page 132 of Dr. Findlay's book—"The Phase Rule and its Applications"*

Turning now to the practical side of the question, we have to consider the nature of the plant to be employed for the operation of crystallisation, which, of course, will include also the dissolving and purification of the liquors before crystallisation is allowed to commence.

The operation of dissolving the crude substance, the purification of the liquors, either by subsidence, by the filter press, or by other means, has already been set out in Chapter II., so that it is not necessary to repeat it here; but we must consider what action the material of which the plant is built has upon the liquors contained in it. One thing not to be forgotten

* London: Longmans, Green & Co. 1904.

in dealing with this part of our subject is the great importance of even traces of impurities in some crystallised products. Traces of iron are especially deleterious in crystals used in dyeing and tanning, and in general *iron* is the *bête noire* to which all the evils of bad workmanship on the part of the purchaser is attributed. It is difficult to keep traces of iron out of many crystals when made in iron vessels, unless the liquors are of an alkaline nature, and the difficulties of construction begin whenever iron in some form or another cannot be employed for the various parts of the plant. Such crystals as sulphate of copper could not be dealt with in iron vessels, and, therefore, wooden vessels, lead-lined, are brought into use, the lead lining not being attacked by the sulphate of copper solution. In fact, lead-lined tanks are very common crystallising vessels, and would be even more suitable were it not for the fact that lead is apt to contaminate the product.

Some solutions, while acting very strongly upon the metal of which the crystalliser is composed in the first instance, become inert in a very

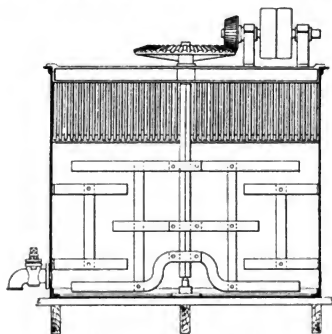


FIG. 164.—DISSOLVING PAN.

short time afterwards. This is the case with solutions of sulphide of sodium, which form the greenish-black hydrated sulphide on first use, colouring and spoiling the crystals for sale, but this action soon ceases, and good crystals can be taken from iron vessels if they are kept in continuous use.

The Preparation of the Solution.—Generally speaking, the raw materials for crystal making are some half product of a previous manufacture, as crude salt-cake for Glauber's salts, and rough alkali for soda crystals,

but there are of necessity many instances where a dilute solution of the substance is evaporated until a certain degree of concentration is reached, when it is run off into crystallisers in order to finish the operation. This is the case with waters from some of the natural alkaline lakes, but generally it will be found that some solid substance requires to be dissolved in water, or some other solution, in order to fit it for the crystallising process. We have an instance of this in the nitrate of soda deposits of Chili, the soda-bearing earth of Egypt, the copper sulphate deposits of Argentina, the Glauberite deposits of Spain, to say nothing of the Stassfurt potash salts which have yielded us so many lessons in chemical technology. The Glauberite deposits of Spain are worked by simply digesting the ground material in water, the sulphate of lime remaining insoluble, while the sulphate of soda passes into solution and is crystallised out, the difference between the night

and day temperatures of that climate being such as to allow the operation to be quickly performed in shallow vessels.

There have been many forms of dissolving pans devised for the purpose of making up crystal liquors, several of which have been used by the author, but no doubt the best type of dissolver is the plain circular tank, with a central agitating shaft, and fitted with a cage to contain the material undergoing solution, as shown in Fig. 164. The cage is constructed of thin iron rods, and lined with strong steel netting of three sixteenths of an inch mesh. It should be placed at such a distance from the top of the dissolver that the base of the cage is always immersed in the liquid, and this will vary according to whether an anhydrous solid, such as soda-ash, or a hydrated crystal, as alum, is to undergo solution.

Unless something prevents, the dissolving pan should be placed at the highest level of the series, as water and liquor may be readily pumped to it, and the material for solution sent up by a hoist or elevator. These appliances have already been described.

Clarification. — When the solution of any material has been made for the purpose of crystallisation, the first step forward is in the direction of purification, or, at all events, of placing the impurities in such a condition that they do not harm the crystalline product. Insoluble substances there are always sure to be in solutions of this kind, and if they are present in but extremely small quantity, they may still be harmful, and even more difficult to deal with than if present in larger quantity. In the making of crystals from Leblanc soda, the traces of the double sulphide of iron and sodium present in the hot concentrated liquor spasmodically produced much trouble, as the running of the liquors from the cooling settlers into the crystallising "cones" down a long wide shute oxidised the sodium sulphide and threw the iron sulphide out of solution. This minute quantity of greenish-black precipitate, though so small as to be practically indistinguishable to the eye when a sample of the liquor was examined in a test glass, settled between the plates of the crystals during crystallisation, the result being a crystal mass of but little commercial value. The student may perhaps inquire how this was remedied, and the reply will serve to show how the process of evolution is developed in chemical operations. The first step was to endeavour to ensure the oxidation of the lower sulphur compounds present in the soda-ash, while the ash was in the carbonating furnace, but it was found that in spite of every care—even though a sample was tested for sulphides before the charge was drawn from the furnace—sulphides were always present in the liquor of the dissolving pan. The next step was to oxidise the sulphides in the dissolver with a solution of bleaching powder, but this, although largely practised, was never deemed thoroughly satisfactory. In some works nothing but a few buckets of cream of calcined magnesia were added to the contents of the dissolving pan, and though this induced rapid settling, it had no action upon the sulphides. A fourth step in the process was the addition of sulphate of lead pulp to the solution, whereby sulphide of lead was formed together with sulphate of soda. The sulphide of lead could have been recovered, but the plan excited some

prejudice on the part of the workmen, and it was given up in favour of a salt which would yield a white precipitate. The "rule of thumb" foreman when he saw that the addition of washed "chamber bottoms"—sulphate of lead—caused the whole contents of the dissolving pan to turn black, could not be persuaded that clean water-white crystals could be produced from it, and, by sympathy of course, the crystals were dark coloured. In former days, it was astonishing how often sympathy prevailed against chemical reactions, but we do not hear so much of it nowadays. Finally, sulphate of zinc was adopted to eliminate the sulphides from crystal liquors, and this proved to be perfectly satisfactory. The need for this special purification is, however, rapidly passing away; soda crystals are not now solely the production of the Leblanc soda ash maker, but are the product of the ammonia-soda maker, and a secondary product in the process of electrolysing common salt. Neither of these sources gives sulphides as an impurity.

But though ammonia-soda does not contain sulphides, the lightly fired variety contains an organic salt of iron which is soluble in the strong liquors, and upon accumulating in the mother liquors communicates a very objectionable yellow tinge to the crystals. There are several ways of dealing with this trouble. By one method the exact quantity of sodium sulphide added to the solution in the dissolving pan produces sulphide of iron, while the organic salt of soda remains behind. By another method, a solution of bleaching powder is added to the liquor in the pan which oxidises both the iron and the organic acid, if the operation is conducted properly, but usually the temperature is sufficient to convert most of the hypochlorite into chlorate and chloride, so that a very large excess of bleaching powder is required. A third method is to add well washed manganese mud to the contents of the dissolving pan, which completely extracts the iron from the liquor. Ordinary manganese mud contains a large proportion of soluble calcium chloride, and this must, of course, be washed away before the mud is added to the contents of the dissolving pan. Every individual substance may require different and special treatment, generally possible of investigation in the laboratory, as the impurities, being of a chemical nature, will respond to chemical treatment. One thing is quite certain, that impurities require careful consideration, as good crystals cannot be produced from bad liquors.

When a finely divided precipitate is suspended in a liquor of high specific gravity, its separation by subsidence is often a slow and unsatisfactory proceeding, and this is the case especially when such a precipitate is small in quantity, flocculent in character, or floating in a liquor having a greater viscosity than water. In such cases, a good subsidence may often be brought about by increasing the volume of the precipitate, or adding to the suspended matters, and this was the reason why the cream of magnesia was added to crystal liquors in the early days of the industry.

The time occupied in settling and cooling has a considerable influence on the capacity of the plant, or, in other words, the total settling room provided must increase with the time of settling. The rate of cooling may be

approximately estimated by means of the formulæ and tables on pages 63 and 66, but the following experiment may prove more useful to those who prefer facts to figures. The settler was of ordinary boiler plate, 10 feet in diameter and 7 feet deep, and ran off each time 500 cubic feet of crystal liquor. A batch of liquor was made up on the 29th of the month of July, and after a few hours' preliminary settling in the dissolving pan it was run into the settler at 5-30 p.m., when it stood 60° Tw. at 88° C. At 6-20 on the morning of the 30th, the temperature had fallen to 71° C., at 12 noon on the same day the temperature was 66° C. On the next day (31st), the temperature at 6-20 a.m. was 49° C., and at 8-20 it was run into the cones, into which it was falling at 43° C. and 65½° Tw. In this case, the pan was not clothed, but freely exposed to the air of the shed all round its periphery. In another case, a clothed pan, 8 feet in diameter and 9 feet deep, took 70 hours to cool down from 94° C. to 27° C.

In many instances, now-a-days, settlers are dispensed with, and the liquor from the dissolving pan is run through a filter-press of ordinary

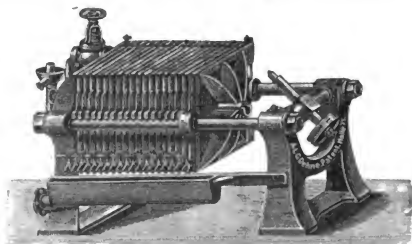


FIG. 165.—FILTER PRESS FOR CRYSTAL LIQUORS.

construction. As the amount of mud is but small in comparison to the bulk of the clear liquor, the press will run much longer before requiring to be emptied than is usual with most filter pressing operations. This modification is perfectly feasible for many crystallisations, but care must be taken to displace any strong liquor remaining in the press at the close of the operation, with water or a weaker liquor, and to start the operation by heating the press, as otherwise the passages may become choked with crystallised salt. A filter press suitable for this kind of work may be seen in Fig. 165.

In making up the solution, it is not always the best mode of procedure to run a fully saturated solution to the crystallisers, though a density should be selected that will give the maximum yield of the precise kind of crystals required. The solution must in each instance be strong enough to yield a fair working crop of crystals, and yet dilute enough to enable it to go through the operations of purification and clarification without depositing crystals which would speedily choke up pipes or shutes through which the liquors are run. The following table (37) shows the specific gravity of various chemical

solutions necessary for furnishing the best crystals, the specific gravity being taken at 100° C. in the dissolving pan, in which the liquor is being made up.

TABLE 37.

SHOWING THE SPECIFIC GRAVITY OF VARIOUS SOLUTIONS AT 100° C. NECESSARY FOR FURNISHING THE BEST CRYSTALS.

Substance.	Sp. gr.	Substance.	Sp. gr.
Aluminium sulphate	1·21	Nickel amm. sulph.	1·15
Ammonia alum	1·16	" acetate	1·26
Ammonium acetate	1·11	" chloride	1·54
" arseniate	1·53	Oxalic acid	1·10
" bichromate	1·25	Potash alum	1·16
" bromide	1·27	Potassium arseniate	1·34
" chloride	1·00	" bichromate	1·36
" hyposulphite	1·36	" bisulphate	1·32
" nitrate	1·26	" bromide	1·39
" oxalate	1·04	" chlorate	1·20
" phosphate	1·34	" chloride	1·21
" sulphate	1·27	" ferrocyanide	1·36
Barium chlorate	1·38	Potassium iodide	1·71
" chloride	1·33	" nitrate	1·25
" hydrate	1·10	" oxalate	1·27
" nitrate	1·15	" permanganate	1·21
Boracic acid	1·05	" sulphate	1·12
Borax	1·20	Sodium acetate	1·18
Bismuth nitrate	1·94	" arseniate	1·34
Cadmium bromide	1·83	" bisulphate	1·34
Calcium chloride	1·45	" bromide	1·62
" hyposulphite	1·46	" carbonate	1·28
" nitrate	1·61	" chlorate	1·44
Cobalt chloride	1·40	" chromate	1·46
" nitrate	1·53	" ferrocyanide	1·23
" sulphate	1·39	" hyposulphite	1·58
Copper acetate	1·04	" nitrate	1·38
" chloride	1·46	" phosphate	1·17
" nitrate	1·62	" sulphate	1·26
" sulphate	1·28	" sulphite	1·21
Ferrous chloride	1·50	Strontium bromide	1·53
" sulphate	1·28	" chlorate	1·83
Lead acetate	1·41	" chloride	1·31
" nitrate	1·54	" nitrate	1·30
Magnesium chloride	1·33	Tartaric acid	1·32
" nitrate	1·46	Tin protochloride	1·97
" sulphate	1·38	Zinc and amm. chloride	1·43
Manganese acetate	1·22	" acetate	1·16
" chloride	1·40	" nitrate	1·62
" sulphate	1·38	" sulphate	1·46

The foregoing table should be employed with much discretion. It will be noted that the sp. gr. given in it does not indicate the strength at which the largest crop is obtainable, but the strength yielding the *best* crystals. Where crystals alone are required, uncontaminated by that block

of solid crystalline matter usually deposited on the bottom and sides of crystallisers, due attention must be paid to the sp. gr. of the solutions shown in the table, but if the yield rather than the appearance is the one object worked for, the sp. gr. of the solutions may be considerably increased. Several instances may be given to emphasise these remarks. At 1.25 sp. gr. at 100° C. a solution of carbonate of soda will yield the maximum quantity of "points" or large crystals in proportion to the "block" or solid cake of crystal covering the bottom and sides, while when the solution is made up to 1.31 sp. gr. at 100° C. the maximum quantity of block is obtained. Again, the best strength for chlorate of potash solutions so as to secure well formed crystals is 1.2 sp. gr., but the solution is not saturated before 1.235 is reached, at which point the temperature has risen to 105° C., the solution containing 486 grammes per litre. The presence of impurities must also be taken into account when using the foregoing table, and this cannot be better illustrated than by reference to the manufacture of chlorate of barium. The figures of the table for barium chlorate show 1.38 as the strength required for the best crystals. Now, barium chlorate is made by dissolving barium chloride and sodium chlorate in water and evaporating the solution to a high strength. During the evaporation, sodium chloride is thrown out of solution, and is removed from time to time with perforated scoops. The evaporation of the liquid and the removal of the salt are continued until the clear liquor is 1.5 sp. gr., when it is run off to crystallise, the crystals being barium chlorate. The difference between the 1.38 of the table and the 1.5 in practice represents the salt held in solution, the cold mother liquor containing 286 grammes of barium chlorate and 182 grammes of sodium chloride per litre, the specific gravity being 1.35. The manufacture of sodium ferrocyanide furnishes us with another example of the necessity of carefully attending to the strength of the liquors required for crystallising. In this case, there is no difficulty in producing solutions at 1.26 sp. gr. at the boiling point of the solution, but directly this touches a cold metal surface the deposit of small grain crystals is so abundant as to practically spoil the whole crop. When the strength of the solution is reduced to 1.23 sp. gr. the difficulty disappears.

The foregoing notes show clearly how careful the manufacturer must be in order to please the customer's eye. It is quite possible that two varieties of crystals may be chemically identical, but if one of them differs in appearance from what is usually found in the market, the maker will often have trouble in disposing of it.

Crystallising.—Crystallisation is generally brought about by absolute repose, although there are instances where it is otherwise. The clarified liquor is run into the crystallising vessels, and there is allowed to remain until the mother-liquor has acquired the temperature of the atmosphere surrounding the vessels. This takes more or less time according to the circumstances of each individual case, and may vary from two or three days to as many weeks.

Soda liquors may be run to the cones at as low a temperature as 27° C., but this temperature will not be satisfactory for all crystals; some require

to be run hot, and it may be said that each substance will require its best temperature to be discovered, and the plant should be arranged for this. When Epsom salts were made in St. Helens from magnesite dissolved in sulphuric acid, the solution was concentrated to the crystallising point in underheat pans, and when the proper degree of concentration had been reached, the liquor in the pan was allowed an hour to settle and then run off to the crystallisers through a filtering box fitted with 20 conical nozzles, to which the filtering cloths were fastened, as shown in Fig. 166. Absolute clarification of the liquors is imperative in all cases of crystallisation, where the crystals are required of good appearance.

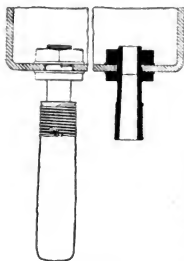


FIG. 166.—
NOZZLE FOR FILTERING BOX.

The shape and capacity of crystallising vessels are made to depend upon the magnitude of the operations. At one time, hemispherical vessels were much in vogue, holding from half-a-ton to one ton of crystal soda, but nowadays rectangular vessels are chiefly preferred, and for soda crystals are made of boiler plate, to hold as much as 14 tons of crystals each. Lead lined wooden tanks are also much used for such purposes as crystallising sulphate of copper, boric acid, chloride of ammonium, and other salts that would attack iron. Cast-iron is, however, largely employed for this last-named salt as, though it acts upon it to some extent, yet the life of such apparatus is a long one, but wrought-iron or steel plate is very rapidly corroded and dissolved away.

A very handy size of "cone" in cast-iron is 12 feet long, 8 feet wide, 2 feet deep in the centre, and $1\frac{3}{4}$ feet deep at the sides. The metal is $\frac{3}{4}$ inch in thickness with strengthening ribs here and there, the top edge being thickened to $1\frac{1}{2}$ inches all round, as shown in Figs. 167 and 168. Sixty-six of these "cones" will produce 100 tons per week of soda crystals on an average the whole year through. When filled with 66° Tw. soda-liquor at 38° C.,



FIG. 167.
CRYSTALLISERS, IN LONGITUDINAL AND CROSS SECTION.



FIG. 168.

and after standing 17 days, each of such vessels will produce 67 cwts. of crystals, of which 18 cwts. will be "points." The small cast-iron cones, $4\frac{1}{2}$ feet in diameter and $2\frac{1}{4}$ feet deep, hold about 24 cubic feet of liquor, and turn out for each crystallising nearly 10 cwts. of soda crystals. Each journey of these small vessels occupies from five to seven days.

The small cones are usually hemispheres, and are useful in smaller installations than are met with in such industries as that of soda-crystals, but in the finer chemicals very much smaller vessels are generally employed. The larger crystallisers are necessarily fixed in position, but the smaller kinds are capable of being moved about by two men, and emptied of their mother-liquor by overturning them. In the larger installations the crystallisers are fixed over a shute constructed of any suitable material, leading to a vessel, called the mother-liquor well. This well should be provided with an open steam supply for the purpose of warming and diluting the liquor, as otherwise it is apt to crystallise, choking the pipes and producing serious inconveniences and delays. Closed pipes should not be employed in this department except when absolutely necessary, and in such cases a small flush of boiling water after each running-off of the mother-liquor will generally suffice to keep them clean and free from crystal. To show the influence of allowing the crystallising to proceed too far, the author once took a litre of the mother-liquor running from the cones during the making of "crystal ash," and allowed it to stand in a flask in the laboratory for three days; it deposited 340 grammes of crystals, which contained 11.6 per cent. of anhydrous sulphate of soda, while the crystals obtained from the cone itself only contained 1.7 per cent.

When the mother-liquors are very acid, good crystallising vessels are often constructed of blue bricks, jointed with acid-resisting cement, and puddled behind with clay. Such crystallisers are employed in the recovery of the sulphate of iron from the waste galvanisers "pickle" when sulphuric acid is used for pickling. One crystalliser, 48 feet long by 8 feet wide and 15 inches deep, will produce six tons of copperas weekly from 60° Tw. liquor after standing to crystallise for seven days. The waste pickle contains 80 per cent. of the acid in combination, but the mother-liquor contains about 80 per cent. of the acid in the free state, and the crystals, drained as well as may be, will contain about 3.0 per cent. of free acid.

It has already been advocated to place the dissolving pan at the highest stage in the series. On the next lower level the settlers should be placed, or if there be no settlers employed, the filtering arrangements should stand on this level, so that while on the one hand the liquors from the dissolving pan may run into the settlers or their substitutes, the liquors from the settlers may be run by gravity alone into the crystallising vessels, and these should discharge their "mother-liquor" into the lowest set of vessels of which the plant consists. It seems, perhaps, begging the question to insist upon all these operations being performed systematically, but when some actual installations come to be considered, it will be found that the caution is not superfluous.

In one works making soda crystals, known to the author, the dissolving pan was placed upon the floor level, and the hot solution pumped into a preliminary settler placed at a higher level: but as it had always cooled considerably during the process of pumping and repairing the pump, the almost clear liquor was run next into a very large pan (called in the works the "Great Eastern"), where it was heated again to the boiling point, and

then run into the settlers proper for complete clarification. These settlers were placed in a very cold situation, and before a thorough clarification was effected the liquor had usually commenced to crystallise. These settlers were not clothed, and so lost heat rapidly, and in order to warm the liquor up again to running temperature, it was the custom to light a fire underneath the settler when it was necessary.

This proceeding produced a circulation of the contents and disturbed the sediment lying upon the bottom of the vessel, and so produced reddish coloured crystals. Suffice it to say that when rule-of-three succeeded rule-of-

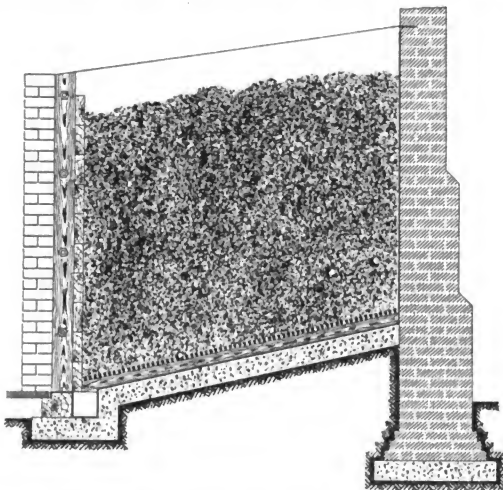


FIG. 169.—A DRAINER FOR ROUGH CRYSTALS.

thumb these settlers were jacketted, and no more fires lighted under them. But now let us follow this badly designed plant through the final stages. The crystallising "cones" were the lesser segments of spheres and were sunk into the ground, the mother-liquor being removed from the cones by means of a scoop with a long handle, and transported from the crystallising shed in an ordinary swing water barrow on two wheels. In this manner and in the good old days, 40 tons of soda crystals were made weekly. It is often the case that more may be learned from failures than from successes, and the description of the foregoing plant will help us to know what to avoid. When crystals are "lifted," as it is termed, from the crystallisers, they are in some

instances placed on drainers in order that the mother-liquor may drain away from them as much as possible. The illustration shown in Fig. 169 is the form adopted for sulphate of ammonia, and it may be used for most other crystalline products. It is really a bin built of blue bricks and lined internally with sheet lead. When empty, the front is open similar to the stalls in a stable, and as the crystals are filled in, loose planks are added in the manner shown in the illustration, which represents the drainer when completely filled. The floor of the drainer is of well-laid concrete sloping towards the ground, where a draining channel is formed, leading to a small mother-liquor well. This channel, as well as the floor, is covered with sheet lead.

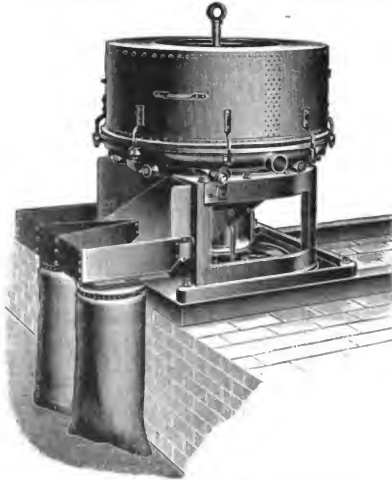


FIG. 170.—HYDRO-EXTRACTOR FOR SODA CRYSTALS.

Upon the floor are placed bearers of suitable material, as timber, blue bricks or tiles, and upon them are placed a number of laths (when the character of the crystal admits) spaced about $\frac{1}{4}$ -inch apart. Such drainers, though fairly efficient for a coarse grain crystal, are not so good for one of very fine grain, as the lowermost foot or so of the material never drains absolutely dry, except by excessively long repose, but this is overcome in many instances by placing this stratum upon the top of the contents of another and newly filled drainer, in which position the operation is finished satisfactorily.

The method most in vogue to-day is to lift the contents of the crystallisers into small trucks running on tramways, or into small overhead "runaways,"

and to convey them direct to a hydro-extractor, where they are dried and bagged, or otherwise packed into casks in a fewer number of minutes than it took days, or even weeks, in the older method. A centrifugal drier made specially for soda crystals and Glauber's salt may be seen in Fig. 170.

So far, we have dealt with crystallisation as a process of repose, and at moderately low temperatures, but this is not always the case, as crystallisation and subsequent separation also take place at much higher temperatures than those already mentioned. Perhaps the most popular instances of this lie in the manufacture of salt and of sulphate of ammonia. In the salt manufacture, the brine is simmered, and the slower the crystals grow the

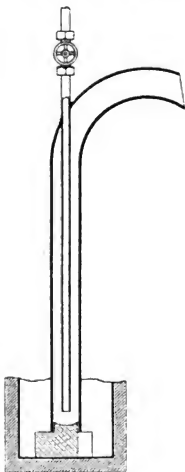


FIG. 171.
NEILL'S CRYSTAL LIFTER.

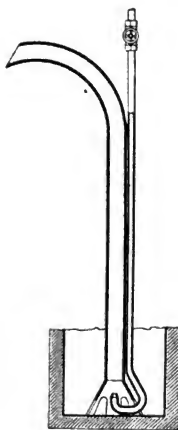


FIG. 172.
WILTON'S DISCHARGER.

larger is the "grain" of the salt produced. The making of fishery salt is *the process* in which to study crystallisation in the warm. Crystallisation starts at the surface of the liquor, and the crystals grow until too heavy to be supported, when they sink through the liquid (brine), and accumulate on the pan bottom. Even in the same pan the sizes of the crystals vary. The front end of the pan furnishes the best quality of "fishery" salt, while the back part of the pan furnishes a No. 2 quality. When a pan is drawn, these two qualities are divided for sale separately. A fishery salt pan will draw about once in every seven days, and during that period from 16 to 20 tons of crystals will have accumulated.

In the manufacture of sulphate of ammonia, ammoniacal gases are passed into a vessel partly filled with diluted sulphuric acid. The ammonia is absorbed and combines with the acid to form crystals of sulphate of ammonia, which at first are small in size and pasty in consistency, so that, as a matter of fact, it is difficult to drain away the mother-liquor from them. When, however, the crystals have grown sufficiently they separate from the liquor easily, and drain well.

One point for the Chemical Engineer to consider, and certainly one of moment so far as the labour question is concerned, is how the crystals shall be removed from the vessels in which they have been formed. With such products as soda crystals, the block of crystals adheres to the side and bottom of the crystallising vessel to such a degree that its removal by a pick is necessary, but with salt, and in the case of small installations of sulphate of ammonia plant, the crystals are generally removed with a hand scoop, in which they are conveyed to a drainer. As already mentioned, some of the

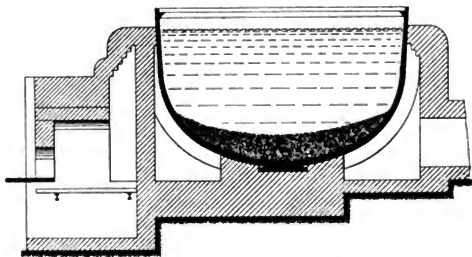


FIG. 173.—CAUSTIC POT WITH SALTS *in situ*.

work is now performed mechanically; finely granulated salts, like sulphate of ammonia, can be lifted in an apparatus constructed very much after the manner of an ordinary air lift or emulseur, and deposited upon a drainer at a higher level than the top of the saturator or other pan, so that the liquor which drains away may find its way back into the pan again. Neill's lifter and Wilton's discharger, Figs. 171 and 172, are both constructed on this principle, the former using compressed air, while the latter uses steam.

Crystals often deposit from solutions during evaporation, and when this occurs the pans must be of such a shape that the crystals, or "salts," as they are always called, can be quickly removed, as, if they were allowed to remain in contact with strongly heated plates, those plates would soon be burned through if of wrought iron, and stand a good chance of becoming cracked if they are of cast-iron. The caustic-soda process teaches us a lesson in this respect. The causticised liquors of the Leblanc process, at the strength at which they commence to be concentrated, are not saturated with any of the constituents, but when about 54° Tw. is reached, mono-hydrated carbonate

of soda and anhydrous sulphate of soda are deposited, or rather these two substances are thrown out of solution, but the ebullition and viscosity of the liquor keep them in suspension. If at this stage the contents of the pot shown in Fig. 173 are allowed to settle, the fire being drawn for this purpose, the clear liquor may be baled off and further concentrated, while the "salts" are fished out with a perforated scoop to be dealt with in various ways. The foregoing is the process that produces so many cracked pots—one of the greatest expenses in caustic making—and a little reflection on the part of the engineer will convince him that this is not the kind of operation suited for a hemispherical cast-iron pot, unless the heating is so arranged as to be capable of instant regulation between very wide limits. What are known as "boat-pans" at one time were extensively employed for the

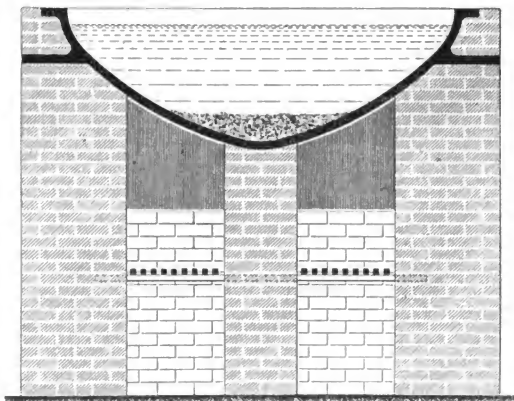


FIG. 174.—SECTION THROUGH BOAT PAN.

evaporation of solutions which deposited salts during the operation. They are still used to some extent, though the system of evaporation by steam in multiple effect is relegating them to the limbo of forgotten things. As they may be of use in new industries, an illustration of one of them is shown in Fig. 174, which exhibits clearly the method of heating. The centre or keel of the pan is made to rest upon a 14-inch wall running under its full length, thus keeping it from the direct influence of the flame at the part on which the salts are likely to deposit. The plates covered by the salts do not then become overheated, unless by negligence in removing them with the perforated scoop provided for the purpose. What are called mechanical pans need not be discussed here, as in the author's opinion the money spent upon them would be better employed in other directions.

The formation and deposition of crystals at the boiling temperature form an important part of several manufactures. At one time a fairly pure glass-makers' alkali was made in St. Helens, but has now been pushed aside by ammonia-soda. It was produced by taking the "salts" from the best pans in Gossage's way of dealing with crude Leblanc liquors, washing them with hot vat liquors, dissolving them, settling the solution, and first forming the ten-atom hydrated carbonate of soda. These crystals were then melted by means of the waste heat from a pot into which the melted crystals were allowed to run. The solution thus obtained was evaporated, and the mono-hydrated carbonate of soda fished out from time to time; this was roasted in the usual "finishing" furnace to produce "crystal ash."

It often happens that when two soluble substances are in solution together one of them will be thrown out of solution in the crystalline form during concentration by heat. Thus, when a solution of nitrate of soda and chloride of potassium is boiled and the water evaporated, chloride of sodium is thrown out in the granular form, while nitrate of potash remains in solution, and crystallises out when the solution is allowed to cool. Sometimes one meets with peculiarities in chemical action. If we mix an equivalent of sulphate of lead with an equivalent of a dilute solution of chloride of calcium, the mixture will remain *in statu quo*, but if we mix one equivalent of the lead sulphate with four or five equivalents of calcium chloride, nearly the whole of the lead sulphate will be converted into lead chloride that can be readily crystallised out. Many modifications of crystallising apparatus may be designed for such crystallisations as these, and if the chemical and physical aspects of the question are thoroughly understood there should be no difficulties in the way of operating successfully.

Re-crystallisation. — When a second crystallisation is necessary, and especially where a preliminary washing of the first crystals is to take place, the rough crystals should be deposited in a coarse granular form, as thorough washing cannot take place when large crystalline blocks are subjected to the washing liquid. This condition can generally be brought about by a gentle agitation of the liquid, or by the injection of air while cooling to the crystallising point—a very short time sufficing for the entire deposition of the crystallisable contents. Such crystals as these are easily washed, easily dried in the hydro-extractor, and are, moreover, much purer as a rule than the large blocks of rough crystals.

In some cases, the crystals from a first crystallising are pure enough for the purposes of trade and commerce. This is the case with soda crystals, Glauber's salt, Epsom salts, and the like, which, though not absolutely pure, need no second crystallisation to eliminate the impurities, as this would be a cost out of all proportion to its usefulness. But there are cases in which a second crystallisation is imperative. The manufacture of alum from shale is a case in point. The rough alum crystals are not dissolved up in water in the usual way, but steam is blown into them, and the strong solution made in this way is allowed to settle and run into crystallising vessels formed after the manner of a wet cask, but slightly conical from top to toe and lined with lead, which by projecting through the staves from the inside

can be "dressed" perfectly tight. This second crystallisation usually eliminates nearly the whole of the iron salts, but if a higher degree of purity is required a third crystallisation will ensure it.

The manufacture of chlorate of potash by the old method serves as an admirable example of the need for re-crystallisation, and it will be also made to serve as an illustration of the methods sometimes employed to get rid of impurities in rough crystals.

Chlorate of potash is made by passing chlorine gas through a mixture of milk of lime in which a certain quantity of "muriate of potash" has been dissolved. The 80 per cent. muriate generally employed for chlorate making contains common salt as an impurity, and as chloride of calcium is formed during the passage of the chlorine through the solution, the first crystals obtained have not a very high degree of purity. The composition of both crystals and mother-liquor may be seen in the following results of their analysis :—

	Rough Crystals. per cent.	Mother-Liquor. grms. per litre.
Potassium chlorate	69.5	27.2
Calcium chloride	8.4	432.9
Potassium chloride	1.1	15.6
Sodium chloride	3.6	15.5
Water	17.2	863.8
	<hr/> 99.8	<hr/> 1355.0

It will be seen at once that the simple re-crystallisation of these "rough crystals" would not result in a very pure finished chlorate, as the mother-liquor from such crystals would contaminate them to such a degree as to render them too impure for sale. It is, of course, the object of the chlorate maker to get all the crystals out of the rough-chlorate liquor that will fall when the temperature has been reduced to that of the surrounding air, and with this is coupled the condition that as small an amount of the foreign salts as possible should crystallise out with them. The analysis of the mother-liquor given above shows that nearly 1½ lbs. per cubic foot of chlorate still remains in that liquor, and this quantity cannot be crystallised out at the ordinary temperature of the air. If the liquor be further concentrated nothing but the three chlorides will crystallise out. If rough chlorate mother-liquor be boiled down to 72° Tw. at 105° C. the composition of the crystals deposited on cooling will be as nearly as possible :—Potassium chloride, 20 per cent. ; sodium chloride, 45 per cent. ; and calcium chloride, 35 per cent. Although the chlorate dissolved in the mother-liquor cannot be separated by further concentration, it has been found possible to cause the crystallisation of a further quantity by artificially reducing the temperature of the liquors by means of refrigerating apparatus, and this process is employed in the most modern chlorate works employing chemical methods.

Let us now turn our attention to the "rough crystals." Approximately, they contain 13 per cent. of chlorides that must be taken away before a

satisfactory crystallisation can be commenced. The best way of doing this is to digest these crystals in a liquor that is already saturated with chlorate of potash. We have such a liquor in the mother-liquor from the finished chlorate, which contains 80 grammes per litre of chlorate and only about 9.0 grammes per litre of chlorides, the greater portion of which is chloride of calcium.

If we take some of the rough crystals of the composition before mentioned, and digest them with a limited quantity of the finished chlorate mother-liquor of 7° Tw., we shall find that the density of the liquor will be increased to 50° Tw. In actual practice, the low density of 7° Tw. is scarcely ever reached, and 11° Tw. or 12° Tw. is much nearer the mark, as the liquors always possess a few degrees of temperature above that of the atmosphere. In practice, also, to perform the process in one operation would not be

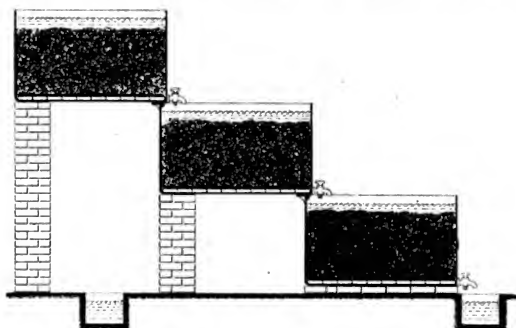


FIG. 175.—APPARATUS FOR WASHING ROUGH CRYSTALS BY DIFFUSION.
(Top tank = A, Middle tank = B, Lowermost tank = C, Lowermost tap D.)

sufficient, as the washed crystals would be heavily charged with liquor at 50° Tw., whereas it is possible by performing the operation in thrice to cause the crystals to leave contact of liquor of not much greater density than the mother-liquor of the first instance, say 11° or 12° Tw.

The method by which this is usually accomplished is to provide a series of three vessels placed one above the other in which the rough crystals are placed and through which the finished chlorate mother-liquor is made to flow, their disposition being shown in the above illustration (Fig. 175).

The rough crystals are first placed in the vessel C, in which a suitable false bottom exists, and liquor from B is run on to just cover them. After remaining in C for a sufficient length of time, the liquor is run off by the tap D, and B being empty at starting, the contents of C are transferred to B, C being filled again with rough crystals. Liquor from tank A is now run on to just cover the crystals in B, when, after sufficient digestion, the liquor

is run off to cover the crystals in C. Now, A being empty, the crystals from B are cast up into it, and finished chlorate mother-liquor admitted to just cover them, the contents of C being transferred to B, and fresh rough crystals being filled into C. In this way, the finished chlorate mother-liquor running on to A at 11° Tw. leaves that vessel at 12° Tw. to cover the contents of vessel B, from which it runs at 33° Tw. to cover the contents of tank C. After it has done its work there, it leaves by the tap D at 50° Tw., having taken up its maximum amount of impurity, and leaving chlorate in solution in about the same proportion as exists in rough chlorate mother-liquor. The rough chlorate originally contains about 13 per cent. of chlorides, but after washing in the above manner it only contains 0.3 per cent. A sample of these washings running from the tap D, and the finished chlorate mother-liquor supplied to tank A, gave the following results on analysis—the results expressed in grammes per litre.

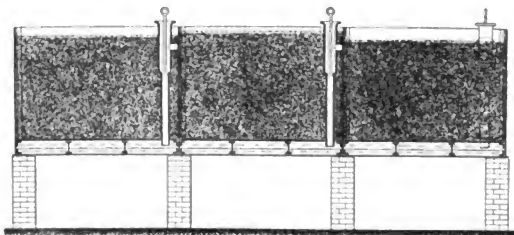


FIG. 176.—VATS FOR WASHING BY DIFFUSION.

	Liquor supplied to tank A.	Liquor drawn from tap D.
Potassium chlorate	81.2	19.6
Calcium chloride	7.1	279.7
Potassium chloride	0.9	13.4
Sodium chloride	1.1	84.4

There is no doubt that the method adopted in the foregoing description is correct in principle, and the results from a chemical point of view entirely satisfactory, but as an engineering problem it was badly solved. The labour involved in lifting the partly washed crystals from tank C to tank B, then to tank A, from which they were subsequently discharged, shows that the correct principle was not grasped by those who were responsible for the construction of the original apparatus. The principle is somewhat similar to that which obtains in the lixiviation of black ash, but with even more favourable conditions: a series of three small vessels, fitted up as black-ash vats, shown in Fig. 176, would have enabled them to have been filled, and the contents to have remained there until the washing was finished, and they were ready for discharging.

The washing of crystals for subsequent re-crystallisation is a subject that has not been sufficiently studied in this country by those manufacturers to whom it would be an important advantage. It has just been stated that the principle is similar to that of the lixiviation of black-ash, but this must be repeated with some qualification. The operation is similar, but the principle is not one of solution, but one of diffusion. It is easy to wash the surfaces of the rough crystals from the adhering mother-liquor but much more than this is required. It is necessary to remove the solution of impurities that lies between the aggregation of crystals, and the plates thereof. Time is required for this liquid diffusion, and without adequate time be allowed the operation will not be efficient. No harm will be done to the crystals undergoing the washing operation by prolonged immersion in a saturated mother-liquor; indeed, good will accrue, as, in taking up impurities, the mother-liquor deposits a large quantity of the pure salt. This may be seen by the analyses on page 356 where the pure crystal mother-liquor contained 81.2 grammes of potassium chlorate, while the liquid running away from the lowermost vessel contained but 19.6 grammes per litre. Moreover, the purer the washed crystals are sent to the re-dissolving pan, the freer will the pure crystal mother liquor be from impurities, and consequently the final stage of washing will be made with purer liquor.

The foregoing illustration has not been given to explain the manufacture of chlorate of potash, but in order to develop the principle, which the author has used in several other ways. The carbonate of soda salts fished out in the ordinary manner from concentrated Leblanc liquors always contain a considerable quantity of impurities, notably of caustic soda, which in most cases it is desirable to remove, especially when the salts are finished into what was known as "carbonate" ash. When these salts are washed with boiling vat liquor a great portion of these impurities are abstracted, and the resulting washed salts stand a much higher degree of heat during the calcination than the unwashed salts. The effect of washing these crystals may be seen by the two following analyses, the first (A) representing the vat-liquor employed, while the second (B) shows the composition of the liquors leaving the washing tanks, after standing upon the salts for one hour. The numbers indicate grammes per litre.

	A.		B.
°Tw. at 73° C.	54	....	56½
Total alkali	210.0	....	217.0
Caustic „	61.0	....	115.0
Sodium sulphide	4.7	....	2.4
„ chloride	16.0	....	34.5
„ sulphate (a)	13.8	....	21.0
„ „ (b)	26.0	....	43.2
Iron reckoned as peroxide	0.16	....	0.23
Alumina	1.92	....	2.86
Silica	1.60	....	2.30
Sodium ferrocyanide	0.72	....	0.94

By sulphate (a) is meant the actual sodium sulphate present in the liquors,

while sulphate (*b*) represents the total sulphur compounds present calculated after oxidation to sodium sulphate. It may be urged that the foregoing example is superfluous seeing that so little Leblanc soda ash is made nowadays—but still the figures are useful in showing how the method of purifying by diffusion may be applied to many other operations. In the author's process for the preparation of sodium ferrocyanide from coal-gas, the first rough crystals would be too impure for sale. They could possibly be made purer in the first crystallisation at the expense of some carbonate of soda loss, and the probability of a smaller yield in ferrocyanide; the foregoing principle has therefore been applied with very satisfactory results. The first rough crystals when lifted from the rough crystallisers and well drained are composed of the following constituents:—

	A.		B.
Sodium ferrocyanide (cryst.)	93·8	....	99·87
„ sulphocyanide (cryst.)	0·4	....	trace
„ carbonate (cryst.)	4·2	....	0·11
„ sulphate (cryst.)	0·6	....	0·02
Other impurities	1·0	....	—
	<hr/> 100·0<hr/>	....	<hr/>100·00 <hr/>

The sample A represents the rough crystals before washing, while the sample B shows the composition of the same after washing, and as leaving the hydro, both air dry. The B crystals when re-dissolved give a commercial crystal almost absolutely pure, the mother-liquor from them containing impurities shown at C in the following analysis, and this after use in the vats for washing by diffusion becomes further charged with impurities as shown by D. The results are expressed in grammes per litre.

	C.		D.
Sodium ferrocyanide (cryst.)	217·8	....	194·5
„ sulphocyanide	traces	....	3·4
„ carbonate (cryst.)	18·9	....	96·2
„ sulphate (cryst.)	3·1	....	13·6

The results given in A, B, C and D are good average working figures, obtained on the large scale when producing about $2\frac{1}{2}$ tons of sodium ferrocyanide per week.

The washing process is, as already stated, one of diffusion, so that the following table (38) showing the diffusion coefficients for various crystalline salts and some acids, may come in useful for comparison, both here and in the section dealing with Dialysis.

The quantity *k* is the number of grammes of substance, which at the temperature *t* diffuse in one day across a stratum one square centimetre in area—if the variation in the concentration, in the direction at right angles to the stratum be unity per centimetre—and if there be at the stratum, *n* grammes of water to 1·0 gramme of substance. The solution of the substance is not separated from the water by a porous diaphragm.

TABLE 38.
DIFFUSION COEFFICIENTS INTO PURE WATER.
(After Scheffer.)

Substance.	<i>t</i>	<i>n</i>	<i>h</i>	Substance.	<i>t</i>	<i>n</i>	<i>h</i>
NH ₃	4.5	16	1.06	NaNO ₃	10.5	18	0.76
"	4.0	85	1.06	"	10.5	95	0.83
PbN ₂ O ₂	12.0	136	0.66	AgNO ₃	7.2	12	0.65
"	12.0	514	0.71	"	7.2	25	0.77
BaCl ₂	8.0	46	0.66	"	7.2	189	0.90
"	8.0	337	0.95	H ₂ SO ₄	8.0	136	1.01
CaCl ₂	9.0	13	0.72	"	8.0	84	1.02
"	9.0	207	0.64	"	13.0	35	1.24
"	9.0	384	0.68	HCl	11	7	2.67
NaCl	5.5	11	0.73	"	11	27	2.12
"	5.5	25	0.73	"	11	69	2.20
"	5.5	52	0.74	HNO ₃	9	35	1.78
"	5.5	58	0.76	"	9	426	1.73
MgSO ₄	10.0	30	0.27	H ₂ C ₂ O ₄	14	415	0.94
"	10.0	248	0.34	"	14	689	1.01

Constructing Tables. — It often happens that in works of any magnitude tables showing the percentage of any given substance in solution are found extremely useful for stock-taking and other purposes. In the older works, but few of such tables existed, owing to the idea then prevalent that tables of the kind required needed a large amount of laborious work in their preparation. It may be well for the student to know that a simple and ready method exists of preparing diagrams, and, consequently tables of the kind required, presupposing, of course, that the liquors are at a standard temperature, and do not vary materially in their chemical composition. The results may be expressed in a variety of ways, as in percentages of the soluble substance; in parts by weight of the substance dissolved in 100 parts of water; in grammes per litre or ounces per cubic foot; or in pounds per cubic foot, according to the systems adopted in each individual works, but for general manufacturing purposes there is no doubt that the system of expressing the weight of a given substance in a given volume of solution is the most generally useful. The method of arriving at this is in most cases simplicity itself, and does not entail a great deal of analytical work. Let us take as an instance the case of chlorate of soda shown by Fig. 177. Upon squared paper draw the vertical axis Y and the horizontal axis X from the point of origin O. Set off upon O — X numbers corresponding to the grammes of substance contained in a litre of the solution, saturated at the standard temperature, which may be readily ascertained by several careful experiments. Numbers corresponding to the specific gravity, or the degrees Twaddell, are then set off on O — Y. If now we plot the grammes per litre against the specific gravity, and draw a straight line from that point to the point of origin O, the number of grammes per litre existing

in solutions of all intermediate specific gravities may be read off upon the diagram. By this method, one determination only of the actual amount of substance soluble in the saturated solution is mentioned, but the student

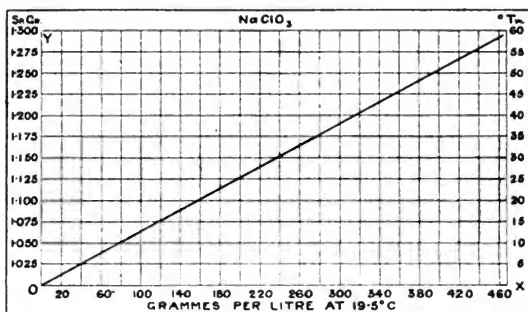


FIG. 177.—SODIUM CHLORATE SOLUTIONS.

should always satisfy himself that the curve is normal, by making several other determinations at intermediate densities, as there are some substances that behave abnormally, though even in these cases the numbers run very near to the straight line.

Another illustration may be given in the contents of sulphate of copper solutions of varying specific gravities. In this case the crystal is hydrated by 5 molecules of water of crystallisation, whereas in the case of sodium chlorate, the crystal is anhydrous. The curve is still a straight line. A

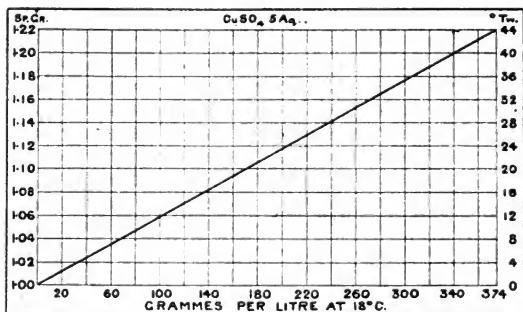


FIG. 178.—COPPER SULPHATE SOLUTIONS ($\text{CuSO}_4 \cdot 5\text{Aq.}$).

saturated solution of copper sulphate at 18°C . contains 374 grammes of crystallised salt per litre, and is of a density of 1.22. These numbers have been plotted on the diagram shown by Fig. 178, and the straight line drawn to the point of origin.

Several careful determinations of the solubility at different intermediate points have been made in the author's laboratory, and the results have been found to fall within the line, and to agree with M. Etard's formula for the solubility at the standard temperature.

It must be clearly understood that the foregoing method is not applicable to the expression of percentages by weight. This may readily be seen by plotting the percentages of copper sulphate by weight, in solutions of various densities, calculated by H. Schiff, appearing in Storer's Dictionary of Solubilities, or from Mulder's table in Comey's Dictionary of Chemical Solubilities (Inorganic).

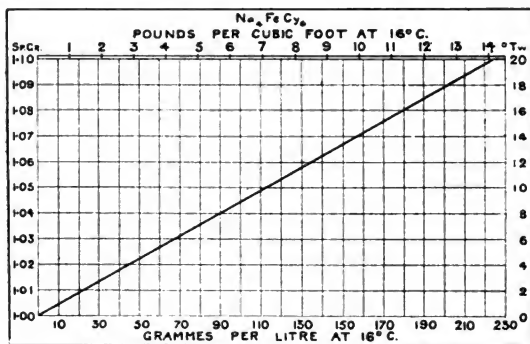


FIG. 179.—SODIUM FERRO-CYANIDE SOLUTIONS ($\text{Na}_4\text{FeCy}_6.10\text{Aq.}$)

Guy Lussac, in his voluminous work on the solubility of various salts, expressed results in parts by weight of the salt, dissolved by 100 parts of water; while others have given their results as parts by weight of salt contained and dissolved in 100 parts of the solution. Etard in his researches adopted the latter mode, but in scientific circles a method is now being adopted of expressing results as so many gramme-molecules of the salt dissolved in a definite number of gramme-molecules of water, a method which it is said allows of the comparison of solubility constants with other physical constants, more readily than by any other mode of expression. For all practical purposes, however, there is no doubt that the expression of results in grammes per litre of the solution is a convenience never to be relaxed when once adopted, and on this account the prominence given to these diagrams must be attributed.

A third instance of this method may be seen in fig. 179, which shows a diagram prepared by the author for use in his ferrocyanide process. Here the solution is one of the ten-atom hydrate ($\text{Na}_4\text{FeCy}_{10}\cdot 10\text{Aq.}$), and the diagram shows how pounds per cubic foot may be read off as easily as grammes per litre, so that laboratory figures may be utilised for stock-taking purposes without any needless calculations.

A saturated solution of the crystallised salt at 16°C. was found to contain 224 grammes per litre at $1\cdot099$ sp. gr., and a line was drawn from this point on the diagram to the point of origin. Careful determinations of the ferrocyanide contents were now made at each specific gravity shown, and they were all found to fall within the line.

The study of solution and crystallisation is interesting at all times, and the student will find the mode of graphic representation a considerable aid in all his experiments. The method may be extended to the solubility of

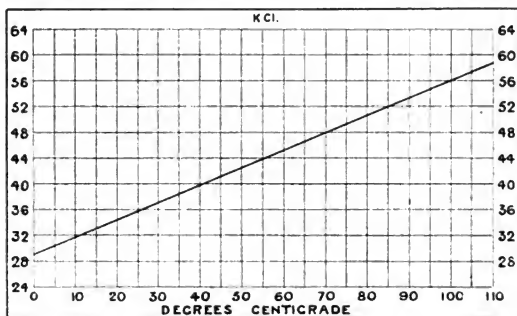


FIG. 180.—SOLUBILITY OF KCl IN WATER AT VARIOUS TEMPERATURES.

various salts at different temperatures, and the results of such plottings are often of a prophetic character. In such "graphs" we have the greatest diversity, from the simple curves of potassium chloride or silver nitrate, to the complex curves of sodium sulphate or ferrous sulphate, and what is foreshadowed in the graph takes place in practice. The solubility curve of potassium chloride in respect to temperature follows a straight line from 0°C. to 100°C. and even beyond, if we plot the results as expressing grammes of the salt dissolved by 100 grammes of water. This may be seen by an inspection of fig. 180.

The solubility at 0°C. is 28.5 grammes in 100 c.c. of water, while at 100°C. one-hundred grammes of water will dissolve 56.6 grammes. If we plot these figures and connect the points by a straight line as shown in the diagram, we are able to read off the intermediate values by the abscissas and ordinates, which show that for 40°C. the solubility is 40.1 grammes, and at 80°C. , 51.0 grammes.

But the temperature solubility curve shown by Fig. 180 is not a common form, and is the exception rather than the rule. Take, for instance, the very abnormal solubility of sodium sulphate shown in fig. 181, which indicates that the amount of salt dissolved increases very rapidly from $0^{\circ}\text{C}.$ to $33^{\circ}\text{C}.$, and then slowly diminishes until $100^{\circ}\text{C}.$ is reached. From $100^{\circ}\text{C}.$ it is extremely probable that the solubility very rapidly diminishes, perhaps in the direction of the dotted line shown in the diagram, as, in the caustic soda manufacture, the liquors are quite free from sodium sulphate when they have arrived at a temperature of $160^{\circ}\text{C}.$, the anhydrous salt having been deposited in the crystalline form during evaporation to that point. Some very interesting information, relating to the behaviour of sulphate of soda in solution, may be found in Dr. Alex. Finlay's book on "The Phase Rule and its Application,"* pp. 131 *et seq.*

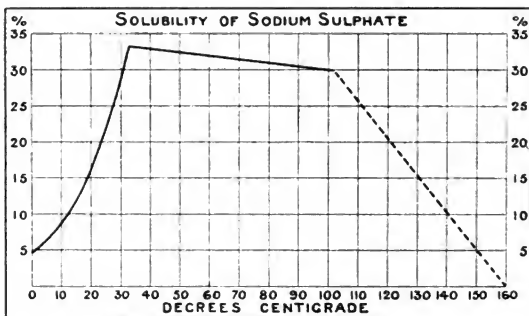


FIG. 181.—THE SOLUBILITY OF SODIUM SULPHATE AT VARIOUS TEMPERATURES.

It seems probable that these and similar observations will be utilised in chemical manufacture in the near future. Gin's process for the preparation of copper sulphate has already been alluded to (page 144), and to this we must refer again. Gin seeks to prepare copper sulphate by lightly calcining the ores of copper in a certain manner, so that the roasted product will contain the sulphates of copper and iron. This is lixiviated, the iron reduced entirely to the ferrous state and the solution heated under pressure, during which operation the ferrous sulphate is precipitated in fine granular crystals, the sulphate of copper remaining in the solution. The magma is then forced through a hot filter-press which retains the whole of the ferrous sulphate, while the iron-free solution of copper sulphate runs away to the crystallisers.† From the researches of M. Etard on saturated solutions at high temperatures it appears that the coefficient of solubility of sulphate of copper reaches a

* London: Longmans Green & Co. 1904.

† Chemical Trade Journal: page 238, Vol. XXXIII.



maximum at a temperature of $105^{\circ}\text{C}.$, and decreases from that point very slowly. The solubility of ferrous sulphate reaches a maximum at a few degrees below $100^{\circ}\text{C}.$, and rapidly diminishes from that point, becoming nil at a temperature just below $160^{\circ}\text{C}.$, so that if the two salts are treated in solution together, no change takes place up to $100^{\circ}\text{C}.$, but at $160^{\circ}\text{C}.$ sulphate of iron is completely precipitated, while the sulphate of copper remains in solution. A diagram of the characteristics of these two solutions is extremely interesting, and may be seen in Fig. 182, which shows the weights of the two anhydrous sulphates contained in 100 parts of the solution at the given temperatures.

Enough has been said to show that the study of crystallisation is extremely interesting in all its aspects, and that there is ample room for the development of the principles upon which the operations are based in many of our chemical manufactures. The subject has by no means been ex-

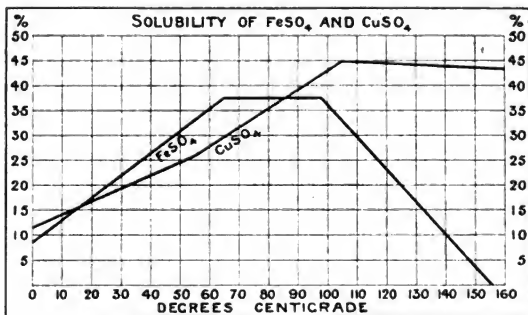


FIG. 182.—SOLUBILITY OF CuSO_4 and FeSO_4 .

hausted, but the principles already set forth will enable the technical student to enquire whether any of them, or which of them, are applicable to his special case.

Preparing for the Market.—The drying and grinding of crystals are not difficult matters, but it is necessary to make a careful study of the chemical properties of each crystal product it is desired to dry or grind. The author has known of several lamentable failures in this direction, but all of them were brought about through ignoring the most elementary principles of chemistry, which, had the engineer been also a chemist, would not possibly have happened.

As a general rule, crystals should not be dried by forcing a current of heated air through a thick bed of them. With anhydrous crystals not much harm is done by such a course of procedure, but if attempted with hydrated crystals, as was once the case at a large sulphate of copper works,

the mass will often cake together, and so spoil the normal crystalline form altogether. Some crystals will dry well enough when placed in thin layers upon shelves in a heated room, from which the atmosphere is continuously removed and changed, or they may be passed through a heated chamber upon a plate conveyor; both these appliances have already been described in the foregoing pages. Some crystals will drain dry without any artificial aid, as in the case of sulphate of ammonia, or carbonate of soda—especially the mono-hydrate—though the operation is hastened in some works, in the former case by the use of a hydro-extractor, and in the latter by placing a stove in the packing room.

Dialysis. — Intimately connected with crystallisation is the study of liquid osmosis, or as it is often termed, "dialysis," which, though not a large operation in this country, is of sufficient importance to be included in a work of this kind.

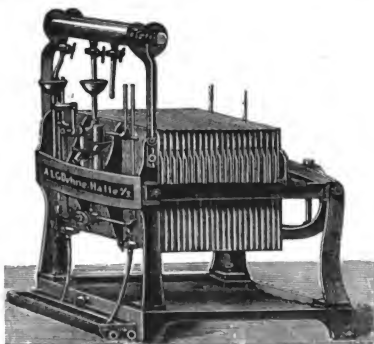


FIG. 183.—DIALYSING APPARATUS OR OSMOGENE.
(By Messrs. Dehne, of Halle.)

If two or more solutions be placed in actual contact, as when a solution of sodium chloride is poured gently upon a solution of potassium chloride so as to form a superposed layer upon it, there will be a constant exchange of molecules between the two liquids until a perfectly homogeneous mixture is the result. This comes about without any agitation or other influence, and it also occurs when the two liquids are separated from each other by an animal membrane, or by a specially prepared vegetable membrane, such as parchment paper. These membranes may be likened to a sieve of exceedingly fine mesh, which allows some molecules to pass through very quickly, while others pass more slowly, and others will not pass through at all. Those substances that will pass through the membrane are called "crystalloids," and those that will not pass through are termed "colloids."

From the foregoing description it will be seen that the operation of dialysis may be either intended to separate crystalloids from colloids when they exist in solution together, or to partly separate several crystalloids from each other when they occur in the same solution. Whether any such separation as is indicated in the latter case is possible or not depends upon the rate of diffusion and upon the degree of concentration required, the rapidity of diffusion varying very much with different substances, see Table 38, page 359. Common salt or chloride of sodium diffuses twice as quickly as cane-sugar or beet-sugar, while sulphuric acid diffuses three times as quickly.

The apparatus designed to carry out the operation of dialysis, and as employed in the beet-sugar factories on the Continent, is built up in much the same manner as the filter-press, and is shown by Fig. 183.

The stand contains a number of wooden frames which are placed *in situ*, in such a manner as to contain the two different liquids, one of which is generally water, while the other is the liquid from which the soluble crystalloids are to be extracted. These liquids are introduced slowly through the two funnels, and passing through the alternate chambers of the apparatus, leave through the exit pipes, in which a hydrometer is placed to control the flow. Once a day the lever on the fixed head-piece is turned over in order that each liquid may enter the chamber previously occupied by the other, and to reverse the direction of motion through the parchment paper. Every three or four days, if the apparatus is in constant use, it should be thoroughly cleaned by passing acidulated water through it, and the parchment paper usually requires changing once a week.

CHAPTER VI.

THE APPLICATIONS OF ELECTRICITY.

It is not the author's intention to present the reader with a dissertation on the general principles of electricity. If these are unknown to the student he cannot utilise the results of special technical investigations, and there is no help for him until he has familiarised himself with the elements of the subject.

The applications of electricity have now become so intimately connected with manufacturing chemistry, that the Chemical Engineer is constrained to know a great deal about them; but as the study will perhaps be somewhat intermittent, the chief figures and co-efficients will not linger so well in his memory as purely chemical and mechanical figures, and therefore the chief object of this chapter will be to furnish electro-chemical information, to which the reader may turn at times to refresh his memory.

Like most other studies of a technical nature, electro-technology has a nomenclature of its own, and with this the student must be familiar before much progress can be made. He must also be acquainted with the various methods of measurement and the practical units employed in every-day work. The units that will concern him most are the "ampère," the "volt," and the "ohm," together with the "watt" and "kilowatt."

To the practical man, the electric current flowing through a conductor may be likened to the flow of water through pipes; the analogy is not perfect, but it is sufficiently near to impress the memory with the exact meaning of the various terms. In dealing with the flow of water in pipes we express the flow as so many gallons per hour under a certain definite "head" or pressure, and we also express the resistance to its flow as so much "loss of head" due to friction. In the electrical analogue we say that a current is flowing of so many amperes at some definite number of volts, and that the resistance of the conductor is a specified number of "ohms."

The reader need not trouble himself in this place with these units in the abstract—they have their history, interesting enough in itself, but as they now each possess a legal value, it is to this we must at once refer. The *London Gazette* of August 24th, 1894, contained an Order in Council setting forth the dimensions of the Ohm, Ampere, and Volt, from which the following abstract has been made:—

1. The Ohm, which has the value 10^9 in terms of the centimetre, the gramme and the second of time, and is represented by the resistance

offered to an unvarying electric current by a column of mercury at the temperature of melting ice, 14.4521 grammes in mass, of a constant cross sectional area, and of a length of 106.3 centimetres.

NOTE.*—A foot length of No. 40 (American wire gauge, Brown and Sharpe's) copper wire possesses, approximately, the resistance of one ohm. A copper wire, ten feet long, of 95 per cent. conductivity, weighing 2 grains to the foot, also possesses the resistance of one ohm. Such a wire is No. 33 on the Imperial Wire Gauge (Table 68, Vol. I., p. 184), having a diameter of 0.01 inch = 10 mils., or 0.254 mm.

2. The Ampere, which has the value 10^{-1} in terms of the centimetre, the gramme and the second of time, and which is represented by the unvarying electric current which, when passed through a solution of nitrate of silver in water in accordance with the specification appended hereto and marked A, deposits silver at the rate of 0.001118 of a gramme per second.

3. The Volt, which has the value 10^8 in terms of the centimetre, the gramme and the second of time, being the electrical pressure that, if steadily applied to a conductor whose resistance is one ohm, will produce a current of one ampere, and which is represented by 0.6974 ($\frac{1}{1445}$) of the electrical pressure at a temperature of 15°C. between the poles of the voltaic cell known as Clark's cell, set up in accordance with the specification appended hereto, and marked B.

NOTE.*—The potential energy of the Volt is equal to 4.673 foot-pounds.

The relation of these units to each other, and to outside quantities may be seen in the following Table:—

TABLE 39..
SHOWING THE RELATIONS AND VALUES OF ELECTRICAL UNITS.

Units.	Symbol.	Relations.	Value.
Ampere	C	Volt ÷ Ohm	The current which will deposit 0.001118 grm. silver per sec.
Coulomb	Q	Amperes per second	do.
Joule	W	Volt × Coulomb	0.2406 calorie.
Kilowatt	kW	Watt × 1,000	737 ft. lbs. per second.
Ohm	R	Volt ÷ Ampere	106.3 c.m. mercury, weighing 14.4521 grms.
Volt	E	Ampere × Ohm	0.6974 of the E.M.F. of Clark's cell.
Watt	VA	Volt × Ampere	$\frac{1}{144}$ H.P.

The ampere-second is called a Coulomb to express current in a given time, but this quantity is too small for manufacturing purposes, and generally the ampere-hour is taken in all such calculations. The ampere-hour is, of course, equal to 3,600 Coulombs. The "ohm" is a near approximation to the Siemens mercury unit, which was largely in use at the date

* Author's Notes.

of the above Order in Council. It consisted of a column of mercury one metre in length and one square millimetre in section, and is about equal to a copper wire of average conductivity, ten feet in length and weighing 20 grains, which corresponds to a thickness of 0.01 inch in diameter.

The ampère is based on similar numbers to Lord Rayleigh's latest investigations upon the deposition of silver from silver nitrate, the amount deposited from the solution by one ampère of current being 0.001118 gramme per second, which is equal to 0.00001035 gramme of hydrogen. The ampère-hour would, therefore, be :—

Silver	..	..	..	..	..	4.025 grammes.
Hydrogen	..	..	..	..	..	0.037 ..

from which all other depositions may readily be calculated.

The volt is the nearest approximation to the E.M.F. of the Daniell cell, which has a voltage of 0.927.

Sources of Electricity.—There is practically only one source of electricity suitable for the electro-chemist, and that is the continuous current from the dynamo of that name. Batteries, thermopiles, intermittent sources of power coupled up to dynamos and accumulators may be disregarded as practical working machines. Moreover, in order that operations with electricity may prove profitable, not only must the dynamo be of the best and most economical construction, but the prime mover—whether it be steam or water-power—must be likewise the best of its kind. It is no use thinking that money may be made now-a-days by grinding out current from an ill-designed dynamo, driven by an ordinary single cylinder high pressure steam engine. The days of such things are gone, and it is only by ensuring perfection in each step of the process that electrolysis can be made profitable. In the works of the Nichols Chemical Company, in the United States—probably the largest electro-refiners of copper in the world—the horse-power consumes no more than twelve pounds of steam per hour.

As to dynamos, it would be quite out of the question to attempt their description in these pages. Dynamos of any and every kind may be purchased, as one can purchase a steam engine, and the same foresight and technical knowledge has to be displayed in one case as in the other. The selection of dynamos for various purposes, such as for electro-plating, electro-refining, or electro-chemical work, is a matter that cannot be lightly undertaken, as a great deal of special knowledge accumulated during the working of those industries must form the basis of any method of selection, especially as during the past ten years improvements in dynamo construction have been so numerous as to preclude their being followed except by those who have made it their daily work. The author does not propose to describe or even illustrate any of the dynamos at present to be found in the market; but if the reader desires to be more fully informed, he should procure Prof. Thompson's treatise on "Dynamo-Electric Machinery," which deals with the subject as fully as the average reader will be able to follow it.

The author desires to impress upon the electro-chemical student the necessity of abandoning low voltage ideas as to dynamos. Low voltage dynamos are wasteful in the extreme, and though they may serve well enough for experimental purposes, yet for manufacturing operations their use is out of the question. In the eighties; the large copper refining works were fitted with low tension dynamos, but they have long ago been displaced by high tension machines. Dynamos yielding currents at a pressure of 100 volts and more will readily yield 90 per cent. of the power applied as current, but it is seldom that the 5 volt machines will return more than 40 per cent. as "watts." Then, again, the resistance to the passage of large currents of low potential becomes a serious matter, whereas the utilisation of small currents of high voltage is comparatively easy, it being much easier to produce and convey small currents of high tension than to deal with large currents of low tension.

As an illustration of the two methods of working let us take an imaginary case of passing a current of 500 amperes through a cell having an opposing electro-motive force of one volt, the resistance of the cell being 0.01 ohm. Substituting these values for C , R and e , which last is the opposing electro-motive force, we obtain, as the energy required :—

$$\begin{aligned} & 500 \times 1 + (500)^2 \times 0.01 \\ &= 500 + 2,500 \\ &= 3,000 \text{ watts.} \end{aligned}$$

If we now take a current of 5 amperes and pass it through 100 tanks in series, each tank opposing one volt, and each having 0.01 ohm resistance, it is evident that the resistance of the 100 tanks will be $100 \times 0.01 = 1$ ohm, and the opposing electro-motive force is 100 volts, so that the watts required in this case will be :—

$$\begin{aligned} & 5 \times 100 + (5)^2 \times 1 \\ &= 500 + 25 \\ &= 525 \text{ watts.} \end{aligned}$$

But the work done in both cases is the same, and it will be seen that the energy consumed with the low tension current is six times that of the current of high tension.

Problems like these can be readily worked out from Ohm's law, which says :—

$$C = \frac{E}{R}$$

C = Amperes.
 E = Volts
 R = Ohms.

When the current contains an opposing electro-motive force e , then

$$C = \frac{E - e}{R}$$

From this we obtain

$$CR = E - e$$

If we multiply both sides by C and transpose, we obtain

$$CE = eC + C^2 R;$$

this term CE represents the "watts" needed to overcome the electro-

motive force e of polarisation (as it used to be called), and to furnish the energy dissipated as heat in overcoming the resistance R .

As to cost of electric energy, it is probable that the figures given on page 306, Vol. I., are too low, and a considerable margin should be allowed. Within the last few years (4) an electric power plant has been erected at the Ellesmere Port works of the Smelting Corporation in Cheshire, from which some useful information may be calculated. It consisted of three double sets of Babcock boilers, fed mechanically with slack and blown by two Sturtevant fans, electrically driven. The dynamo room contained two pairs of cross-compound engines and two dynamos of 400 kilowatts each, while spread about the works were various motors to the tune of 640 h.p. in the aggregate. The cost of this installation complete was £33,000.

A striking instance showing the value to a community of cheap electrical energy is the City of Buffalo. Barely five years ago (1899) Buffalo inaugurated its system of electric energy supply from Niagara Falls, yet already nearly one-half of the horse-power required to operate the vast amount of machinery within the limits of the city comes from this source. Not only so, but a great impetus has been given to the industrial growth of Buffalo, many manufacturing establishments having settled there recently to secure the advantages to be derived from electrical energy cheaply generated by water power. An estimate of the water powers developed in the several countries was given by Herr A. Gradenwitz in a paper read in February, 1904, before the Frankfort Congress of German Naturalists and Doctors. His figures are as follow:—Germany and Austria, 180,000 horse-power; Switzerland, 160,000 horse-power; Sweden, 200,000 horse-power; the United States, 400,000 horse-power. He estimates the total power available in a number of countries to be:—Sweden, 2,000,000 horse-power; France, 10,000,000 horse-power; Germany, Austria, Switzerland, and Italy combined, 10,000,000 horse-power; while in the United States the Niagara Falls alone could furnish 10,000,000 horse-power.

Another instance of the possible economies that may accrue from the substitution of the electric current for coal in certain situations may be gleaned from a paper read by Mr. Mervyn Smith before the Institution of Mining and Metallurgy in December, 1902, on "Electric Power at the Kolar Gold Field." This gold field is situated on the Mysore plateau in Southern India, and the mines are worked by eleven companies separately constituted. The power consumed at the mines averages about 10,500 h.p. which is generated from 190,000 tons of coal, costing £230,000 annually. Amongst the eleven companies there are 366 steam boilers, of which 216 are constantly in use, and the prime cost of these, with the houses, chimneys, etc., runs up the cost of engine power worked by steam to more than £30 per h.p. annually.

Mysore has no coal fields of its own, so that the mining companies are dependent for their supplies upon Singerini, with 600 miles of railway carriage, or upon Barrakar in Bengal, which is 400 miles by rail and 1,000 miles of sea carriage. These disadvantages have led to the installation of a very large electric power plant at the Cauvery Falls, 92 miles from the

Kolar Gold Fields, and from these falls nearly 5,000 H.P. are transmitted to Kolar, to work electric motors there. The motors at present employed are 32 in number, of a total capacity of 4,205 H.P.; of these, 11, with a total capacity of 1,530 H.P., are used to operate crushing mills, and 12, with an aggregate capacity of 2,550 H.P., operate air-compressors. Five motors, of an aggregate capacity of 60 H.P., are used to work hoists and other elevators; 2, with a total capacity of 50 H.P., operate stone-breakers, while one of 10 H.P. runs in the machine shop.

The dynamos are driven by five 60 in. Pelton wheels of 1,250 B.H.P. each, a sixth being held in reserve. They each consume 37 cubic feet of water per second; and the effective head at the wheel being 382 feet, we shall find from the formula given on page 317, Vol. I., that the current received from the transformer house represents a little more than 62 per cent. of the energy of the water taken from the falls, the mechanical efficiency of the Pelton wheel being 77 per cent.; the difference being lost in various ways. The nozzles of the Pelton wheels are fitted with a very efficient governor.

The transmission of the current from the falls to the gold fields (92 miles) is effected by two parallel lines, 60 ft. apart; there are three wires on each line, 40 ins. apart, forming an equilateral triangle. The poles are placed 130 ft. apart, and the lower wires are 20 ft. from the ground. Each line of three wires is of sufficient capacity to transmit the full power at a slightly increased potential, to meet emergencies in the way of break-downs, but in ordinary working, both lines will be used for the transmission, each carrying half the current.

The current is generated by 3-phase alternators with a revolving field and stationary armature, the rated output being 720 kilowatts at 2,200 volts. The current is transmitted from the power house to the transformer house, where 12 static transformers, each of 400 kilowatts capacity, raise the potential to 30,000 volts. These transformers are kept cool by a current of air supplied from several electrically driven air-compressors. On reaching the Kolar gold field, the high voltage current is reduced in potential by a group of twelve transformers to a standard of 2,300 volts, at which it reaches the distribution circuits. The total weight of copper in the transmission amounts to 938,000 lbs., and in the distributing wires to 182,000 lbs.

All motors of 200 H.P. and under are of the induction type, without brushes, collectors or commutators. Sizes of 200 H.P., 150 H.P. and 100 H.P. are wound for 2,080 volts and connected directly to the distributing mains, and all the smaller motors are wound for 220 volts, smaller step-down transformers being used between the distributing mains and the motors. Mr. Mervyn Smith, in his account of the installation says, "the total loss in transmission between the generators at one end and the motors at the other end of the system is approximately 20 per cent., an output of nearly 5,000 H.P. at the Falls power station being requisite for the delivery of 4,000 H.P. at the Kolar Gold Field." It is further stated that the loss of power in the line transmission alone is calculated at 13 per cent. when all of the six wires are carrying the current. If only three wires were used, the loss is doubled.

The total cost of the plant has been as follows:—

Hydraulic plant	£26,500
Electric plant, generators, etc.	112,000
Distribution plant	53,000
Channels, buildings, etc.	148,600
	<hr/> £340,100 <hr/>

It appears that the present arrangements with the mining companies is for the supply of 4,000 H.P. for a period of ten years. The rate per H.P. per annum varies during the first five years from £29 to £18, the average being £20 4s. For the second five years a uniform rate of £10 per H.P. per annum is to be paid by the mine-owners.

It is not unusual to find a manufacturer who has installed a dynamo in his factory expressing the opinion that his electricity is costing him nothing, and owing to this way of looking at things it is very difficult to arrive at the cost of current with accuracy. The author believes that the only way to arrive at an accurate account of cost is to take the figures from the Board of Trade Electricity Supply Works accounts such as are shown in Table 40. It appears from this table that the average cost at the generating stations of ten selected works was (in 1898) 1·41 pence per kilowatt, or Board of Trade unit.

TABLE 40.
ELECTRICITY SUPPLY WORKS COSTS IN 1898.

		Output in 1,000 units sold.	Fuel cost per unit pence.	Wages** per unit.	Repairs and Maintenance.	Generat- ing costs per unit.	Total costs.*
Manchester	M	477·3	0·415	0·166	0·190	0·96	2·84
Birmingham	C	172·2	0·689	0·396	0·219	1·42	4·48
Edinburgh	M	417·5	0·424	0·146	0·116	0·73	2·59
Glasgow	M	282·4	0·544	0·288	0·226	1·12	3·38
City of London	C	694·0	0·939	0·348	0·305	1·74	6·25
Oxford	C	37·4	0·652	0·552	0·595	1·85	6·85
Worcester	M	47·4	0·614	0·482	0·100	1·30	4·15
Brighton	M	264·9	0·644	0·310	0·158	1·20	2·60
Taunton	M	17·1	1·225	0·532	0·140	2·09	5·65
Walsall	M	13·8	0·622	0·435	0·381	1·66	5·41
Average		242·4	0·676	0·365	0·243	1·41	4·45

* Wages at generating station only.

* This column represents total costs plus 6% of mean capital expenditure per unit sold.

M = Municipal.

C = Company enterprise.

Conductors.—Solid copper wires and cables of varying numbers of strands are usually employed for transmitting electric energy. Aluminium has been proposed and is actually in use, but must be considered

upon its trial. The copper wire employed for electrical purposes is very constant in its electrical properties, and is considered of good quality when 100 inches of wire, weighing 100 grains, has a resistance of 0.1516 ohms at 60° F. The resistance of a cable of 91 strands of No. 11 wire, 1,000 yards long, is but 0.025 of an ohm. Such a cable is equal in area to a plain wire of one square inch cross section.

It is easy to fix upon the necessary dimensions for a wire or cable to convey a definite electric current, but before proceeding to that subject it would be as well to examine first the effect of sending a current through a conductor which offers any definite amount of resistance.

TABLE 41.
SIR WILLIAM PREECE'S FUSE TABLES.

Current in Amperes.	Copper Wire.		Iron Wire.		Tin Wire.		Lead Wire.	
	Diameter Inches.	A'prox. I.W.G.	Diameter Inches.	A'prox. I.W.G.	Diameter Inches.	A'prox. I.W.G.	Diameter Inches.	A'prox. I.W.G.
1	0.0021	47	0.0047	40	0.0072	36	0.0081	35
2	0.0034	43	0.0074	36	0.0113	31	0.0128	30
3	0.0044	41	0.0087	33	0.0149	28	0.0168	27
4	0.0053	39	0.0117	31	0.0181	26	0.0203	25
5	0.0062	38	0.0139	29	0.0210	25	0.0236	23
10	0.0088	33	0.0210	24	0.0334	21	0.0375	20
15	0.0120	30	0.0283	22	0.0437	19	0.0491	18
20	0.0150	28	0.0343	20.5	0.0526	17	0.0595	17
25	0.0181	26	0.0408	19	0.0614	16	0.0690	15
30	0.0205	25	0.0450	18.5	0.0684	15	0.0772	14
35	0.0227	24	0.0498	18	0.0759	14.5	0.0851	13.5
40	0.0248	23	0.0543	17	0.0824	13.5	0.0924	13
45	0.0268	22	0.0589	16.5	0.0889	13	0.1012	12
50	0.0288	22	0.0632	16	0.0953	12.5	0.1074	11.5
60	0.0323	21	0.0714	15	0.1101	11	0.1237	11
70	0.0350	20	0.0791	14	0.1220	10	0.1371	10.5
80	0.0364	20	0.0864	13.5	0.1334	9.5	0.1512	9.5
90	0.0377	19.5	0.0933	13	0.1443	9	0.1621	9
100	0.0387	19	0.1003	12	0.1549	8.5	0.1731	8
120	0.0416	17.5	0.1133	11	0.1748	8	0.1942	7
140	0.0442	17	0.1243	10	0.1937	7	0.2177	6
160	0.0464	16	0.1352	9.5	0.2109	6	0.2370	5
180	0.0480	16	0.1461	9	0.2277	5	0.2573	5
200	0.0495	15	0.1562	8	0.2437	4.5	0.2731	4
250	0.0547	13.5	0.1848	7.5	0.2791	3.5	0.3131	3

Whenever an electric current is passed through a wire of copper, or any other metal, the wire becomes heated, and the larger the current, and the longer the wire, the greater the heat developed, so that

by increasing the current, or diminishing the size of the wire, we ultimately reach a set of conditions under which the wire fuses. Sir William Preece has investigated this matter thoroughly, and is the author of a Table setting forth the sizes of various wires which will be fused by a given current. These numbers are to be found in Table 41.

If we take the unit of heat as the amount required to raise one gramme of water from $0^{\circ}\text{C}.$ to $1.0^{\circ}\text{C}.$, and the mechanical equivalent of heat on the C.G.S. system to be, $J = 4.24 \times 10^7$, and if E be the difference in potential between the two ends of a wire, then the work done in moving Q units of electricity from one end of the wire to the other, is:—

$$W = QE$$

$$\text{and as } Q = Ct, \text{ then } W = CEt$$

$$\text{From Ohm's law } E = CR$$

$$\therefore W = C^2 Rt$$

If H = the number of gramme heat units developed in t seconds we have

$$W = JH, \text{ and } JH = C^2 Rt,$$

$$\therefore H = \frac{C^2 Rt}{J}$$

In practical units this becomes:—

$$H = \frac{C^2 Rt \times 10^{-2} \times 10^9}{4.24 \times 10^7} = \frac{C^2 Rt}{4.24} = C^2 Rt \times 0.24$$

H is the amount of heat generated in the wire by the given current in one second. To arrive at the temperature to which the conductor will be raised we must know its weight and specific heat. If W be the weight in grammes, and s the specific heat,

$$H = WTs, \text{ where } T = \text{the temperature, and therefore}$$

$$T = \frac{H}{Ws} = \frac{C^2 Rt \times 0.24}{Ws}$$

This is the temperature attained in the first second before it has become high enough to lose appreciably by radiation and by contact with air as already described on pages 62-67. It will, however, be recognised that T grows proportionately with t until the heat generated by the current has accumulated sufficiently to create that temperature difference between the heated wire and the surrounding medium necessary for its dispersion. If we suppose a current of 10 amperes to be passed through one thousand metres of copper wire of 1.0 mm. diameter, we shall find that the wire will be quickly heated to about $82^{\circ}\text{C}.$, while there will be a drop in potential of about 213 volts, the heat generated and the heat dissipated will now balance each other, so that the temperature of the wire remains stationary at $82^{\circ}\text{C}.$ Our formula indicates:—

$$T = \frac{C^2 Rt \times 0.24}{Ws} = \frac{100 \times 21.28 \times 0.24}{7,000 \times 0.1} = 0.729$$

so that, as $0.729^{\circ}\text{C}.$ is attained in the first second, the maximum and constant temperature would be reached in a little over 112 seconds.

To take another instance. Let us suppose a current of 10 ampères to be passed through one thousand metres of copper wire 10 mm. in diameter having a resistance of 0.21 ohms, in which case it will be found that the permanent rise in temperature does not exceed 0.1° C., and the drop in potential is slightly less than 2.2 volts. Our formula gives us for the heat generated in the first second:—

$$T = \frac{10^2 \times 0.21 \times 0.24}{698,000 \times 0.1} = 0.000723^\circ \text{C.}$$

the maximum temperature having been reached in about 138 seconds.

Tables have been constructed for exhibiting the rise in temperature of wires of specified diameter when passing various currents, and these will be found useful in saving many intricate calculations. Such a table may be found in Dr. A. Neuberger's *Kalender für Electrochemiker*, published by M. Krayn, of Berlin.

TABLE 42.

SHOWING THE DIMENSIONS, RESISTANCE, WEIGHT AND CAPACITY OF PURE COPPER WIRES.

I. W. G.	Diam. inch.	Diam. mm.	Area Sq. ins.	Resistance Ohms per 1,000 feet.	Weight in lbs. per 1,000 feet.	Safe working current.	Brown and Sharpe (American)
1	.300	7.62	.07068	.1133	272.3	137	.2893
2	.276	7.01	.05983	.1339	230.4	117	.25763
3	.252	6.40	.04988	.1606	192.1	98	.22942
4	.232	5.89	.04227	.1895	162.8	84	.20131
5	.212	5.38	.03530	.2269	136.0	70	.18194
6	.192	4.88	.02895	.2766	111.5	56	.16202
7	.176	4.47	.02433	.3292	93.7	48	.14428
8	.160	4.06	.02011	.3984	77.5	40	.12849
9	.144	3.66	.01620	.4918	62.7	32	.11443
10	.128	3.25	.01287	.6224	49.6	25	.10189
11	.116	2.95	.01057	.7579	40.7	20	.09074
12	.104	2.64	.00849	.9429	32.7	17	.08081
13	.092	2.34	.00665	1.2048	25.6	13	.07196
14	.080	2.03	.00503	1.5934	19.4	10	.06408
15	.072	1.83	.00407	1.9672	15.7	8	.05706
16	.064	1.63	.00322	2.4897	12.4	6	.051709
17	.056	1.42	.00246	3.2519	9.5	5	.05082
18	.048	1.22	.00181	4.4262	7.0	4	.0493
19	.040	1.02	.00126	6.3737	4.8	3	.03586
20	.036	0.91	.00102	7.8689	3.9	1	.03196

A copper wire of No. 19 I.W.G. has a diameter of 0.04 inch, and would convey a current of 2 ampères with a drop of 44 volts in 300 yards; but if a current of 5 ampères be sent through such a wire, the loss in potential would be nearly 110 volts, and the wire would be heated to at least 21° C. above the temperature of the air. If we were to increase the current to 80 ampères the wire would fuse.

The last column headed "Brown and Sharpe (American)" simply shows the diameters in decimal parts of an inch of the numbers on that gauge from 1 to 20, and has no connection with the other columns of the table.

When the heat caused by the resistance of the conductor is readily dissipated, as in the case of naked wires, a larger current may be passed than in the case of insulated wires, where the heat is not so readily dissipated, and in which the temperature must not be allowed to rise unduly on account of the perishable nature of the covering at high temperatures. For naked wires and for currents below 200 ampères the following formulæ will give approximately the safe current that may be passed by wires of varying dimensions. They refer more particularly to Table 42.

If W = the weight of copper in lbs. of the given length of conductor,
 R = the resistance in ohms of that length, and
 C = the safe current in ampères,

$$\text{then } \frac{8W}{R} = C^2, \text{ and } W = \frac{C^2 R}{8}$$

By Table 42, 1,000 feet of No. 10 wire weighs 4.8 lbs., and possesses a resistance of 6.3737 ohms, so that the safe current in ampères would be :—

$$\sqrt{\frac{8W}{R}} = \sqrt{\frac{4.8 \times 8}{6.3737}} = 2.45.$$

and for a rod, one square inch in section, the formula yields :—

$$\sqrt{\frac{8 \times 11,740}{0.025}} = 1,938 \text{ ampères.}$$

For currents above 200 ampères, conductors should not be pressed at this high rate, and a good practical rule is not to exceed one thousand ampères for each square inch of section.

For covered wires and cables, the limit of safe working current is less than the foregoing, and a formula has been given in the Institution of Electrical Engineers' rules for 1897, which works out to 750 ampères to the square inch of section. This formula is :—

$$\log C = 0.82 \log A + 0.415$$

where C is the current in ampères, and A the area of the conductor in thousandths of a square inch.

In the year 1900, several of the larger British cable makers issued a specification for conductors with a view to standardisation, and this list, given as Table 43, came into operation on October 1st of that year. In the table, as given here, a column has been added, showing the working current allowed in the German regulations for equal areas, or approximately so.

The "watts" or energy lost by reason of the resistance of the conductor will give us some insight into the reason why we should not attempt to convey large currents through wires of minimum area. The formula

$$C^2 \times R = \text{loss in watts,}$$

and 746 watts make one horse-power. If we refer to Table 43, we shall

find that a 91/12 cable (nominally one-inch square sectional area) is rated to carry a current of 600 amperes. The resistance is 0.025 ohm for one thousand yards of such cable, so that the "watts" lost would be:—

$$\text{For } 1,938 \text{ amperes} = (1,938)^2 \times 0.025 = 92,896$$

$$\text{For } 1,000 \text{ amperes} = (1,000)^2 \times 0.025 = 25,000$$

$$\text{For } 750 \text{ amperes} = (750)^2 \times 0.025 = 14,062$$

$$\text{For } 600 \text{ amperes} = (600)^2 \times 0.025 = 9,000$$

That is to say, by trebling the current the loss of energy has been increased tenfold.

TABLE 43.

STANDARD SIZES OF CONDUCTORS FOR ELECTRIC SUPPLY MAINS.

Nominal size of Conductors in square inches.	No. and Diameter of Strands.	Resistance in standard Ohms per 1,000 yards.			Weight in lbs. per 1,000 yards.		Current.
		Calculated.	Maximum allowable.	Maximum allowable for tinned wires.	Calculated.	Minimum allowable.	Ampères.
.05	7/.095	.490	.490	.504	580	568	—
.05	19/.058	.488	.498	.503	591	580	80
.1	19/.082	.244	.240	.252	1182	1158	—
.125	19/.092	.194	.198	.200	1488	1458	130
.15	19/.101	.160	.163	.165	1781	1745	160
.15	37/.072	.163	.166	.168	1776	1740	—
.2	37/.082	.125	.128	.129	2303	2257	200
.25	37/.092	.0907	.102	.103	2600	2842	230
.3	37/.101	.0827	.0843	.0852	3494	3424	300
.35	37/.110	.0697	.0711	.0715	4145	4062	—
.4	37/.118	.0606	.0618	.0621	4772	4677	—
.4	61/.092	.0605	.0617	.0623	4781	4685	400
.5	61/.101	.0502	.0512	.0517	5762	5647	—
.6	61/.110	.0423	.0431	.0433	6836	6666	—
.6	91/.092	.0405	.0413	.0417	7134	6991	—
.7	91/.098	.0357	.0364	.0368	8094	7932	—
.75	91/.101	.0356	.0343	.0346	8597	8425	—
.8	91/.104	.0317	.0323	.0327	9115	8933	—
.9	91/.110	.0283	.0289	.0290	10200	9996	—
1.0	91/.118	.0246	.0251	.0252	11740	11510	600
1.0	127/.101	.0239	.0244	.0246	11910	11680	—

The drop in volts may be found from $C \times R$, and for the above instances would be 48.45, 25.00, 18.75, and 15.00 respectively. Let us take another instance, that of a single wire of No. 8 I.W.G. If we refer to Table 42, it will be seen that it will safely carry a current of 40 amperes, and a calculation will show the drop in volts to be 53.3 and the heating 21°C . If we now reduce the current to 20 amperes, the drop in volts will be 26.6 and the heating 5°C .; while, if we increase the current, making it 100 amperes, the drop in volts will be 133 and the heating 128°C .

Measuring Instruments.—The foregoing calculations may be found of much use in many instances, and serve to show how the subject

can be approached theoretically, but in practical working ampères and volts may be read off upon special instruments as readily as temperatures are read off upon thermometers or pyrometers or pressure upon pressure-gauges. It is necessary, however, to understand the principles upon which such instruments are constructed, as the "voltmeter" or "ammeter"—as these measuring appliances are called—are just as likely to go wrong as thermometers, pyrometers or pressure-gauges.

The construction of the galvanometer type of voltmeter is based upon Ohm's law, and the proportions of current and E.M.F. in a fixed circuit. Ordinary continuous current voltmeters are, in fact, galvanometers of large resistance, proportioned to the currents to which they act as shunts, while the ammeters are galvanometers of little or no resistance, being made with but few turns of thick wire, through which the whole current passes. Every maker has his own form of construction, but the following illustrations will enable the student to get a good grasp of the principles which underlie most forms of construction.

The brass bobbin shown at A is wound with covered copper wire of sufficient diameter, to carry the current without undue heating. Generally from six to twelve turns of the wire round the bobbin are found sufficient to produce a magnetic flux of the proper density for acting upon the magnet controlling the pointer of the gauge; but of course this detail must depend upon the current to be measured. As already mentioned, the whole current to be utilised passes through the wire, so that in this form of instrument the ammeter is always in the active circuit. The two ends of the wire are connected to terminals placed in an accessible position.

Into the hollow of the bobbin shown at A, the device shown by Fig. 185 is inserted. It consists of a brass mount C holding two magnets M and M', which are the fundamental parts of the system. Underneath these magnets (or, to be more correct, soft iron pieces) is placed a light brass

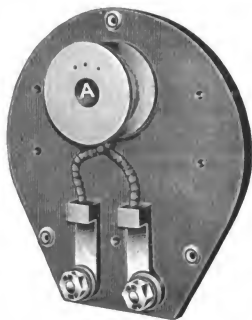


FIG. 184.—
INTERNAL ARRANGEMENTS OF AMMETER.

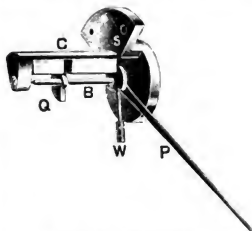


FIG. 185. BALANCED
POINTER AND MAGNETS OF AMMETER.

rod B pivoted upon needle points, and having at one end a light pointer P balanced by the weight W so as to set it at 0 on the scale. Upon this rod is also fixed a soft iron sector Q, which, being free to move between the ends of the magnets M and M, is attracted by them when the current passes, and thus causes the pointer to move over the scale. This device when inserted in the centre of the coil (A, Fig. 184) is fixed to the bobbin by the screws S S, and the construction of the ammeter is completed, save the glazed brass case that covers and protects it.

Voltmeters are of several forms of construction, but we need only examine one form, such as can be kept in the circuit continuously during the time the current is passing. A voltmeter of this form of construction may be seen in Fig. 186.

The bobbin at A is intended to receive the device already illustrated by Fig. 185, both of which, therefore, require no further description. The

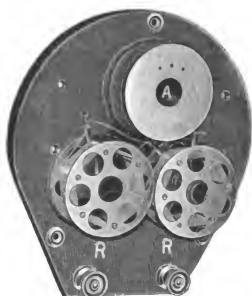


FIG. 186. DETAILS
OF VOLTMETER CONSTRUCTION.

coil surrounding A, however, instead of being composed of a few turns of thick wire, as in the case of the ammeter, is wound with many turns of a finer wire. The illustration also shows two resistances R and R interposed in the circuit. The action of the voltmeter is similar to that of the ammeter. When the current flows through the coil A, the soft iron bars M and M (Fig. 185) become magnetised and attract the quadrant Q, thus causing the pointer to move over the scale; but as there is practically no resistance in the coils of the ammeter, while a considerable resistance occurs in the coils of the voltmeter, and but a small portion of the current passes through, the varia-

tions in the E.M.F. alone affect the magnets.

In practice, the voltmeter, the ammeter, and the necessary switches, fuses, etc., are usually fixed upon a slab of marble, slate, or similar non-conducting material called a "switch-board." This may vary from the simple form shown in Figure 187, which represents that in the author's laboratory, to arrangements of greater complexity. It is not necessary to do more here than to show how a simple switch-board is connected up to a main supply.

The illustration is a front view, showing the position of the various details—the voltmeter, the ammeter, the switch itself, and the two fuses, each of which carries four lead wires of such a capacity that if a current passes exceeding that for which the installation is rated these wires fuse and the current ceases to flow.

The connections at the back of the switch-board may be seen in the diagram Fig. 188. The current enters at +, passes through the ammeter,

through the fuse and reaches the switch; then passing through the switch, travels through the second fuse and leaves the board at —. The position of the shunt in respect to the voltmeter is also shown.

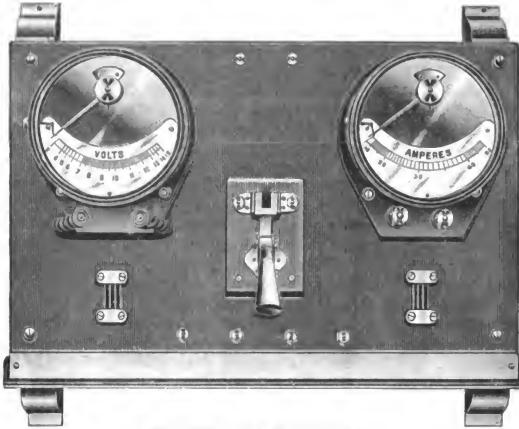


FIG. 187.—SIMPLE SWITCH-BOARD.

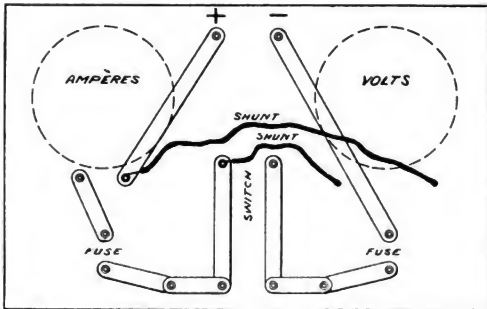


FIG. 188.—BACK OF SWITCH-BOARD.
(Showing Connections.)

The ordinary sector form of voltmeter cannot be used to measure the difference in potential of alternating currents. For these a quadrant electro-

meter is often employed, or the "hot-wire" instruments, as originally suggested by Capt. Cardew, in which the indications depend upon the expansion of a long thin wire, heated by the current. One form of hot-wire instrument largely in use is made by Messrs. Johnson and Phillips, details of the construction of which may be seen in Fig. 189. On referring to the illustration, it will be seen that the hot-wire A A is stretched between two terminals, T_1 and T_2 . Near the centre of this wire, another wire of phosphor-bronze, B, is attached at right angles, and held taut by a third terminal, T_3 . About the centre of this phosphor-bronze wire, a fibre, C, is fixed by one end, the other end passing round a specially grooved roller R, and finally terminating in a small eyelet attachment which is passed over the flat steel spring S. The whole arrangement is thus subjected to tension, and any "sag" of the measuring wire, occasioned by expansion under heat, is taken up by the steel spring, and is transmitted to the grooved roller which carries the pointer. Both ammeter and voltmeter are similar in construction, except that a thicker hot-wire is used in the ammeter than in the voltmeter, and a shunt is substituted in the former for the resistance

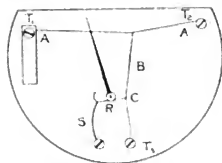


FIG. 189.—HOT-WIRE AMMETER.
(Messrs. Johnson and Phillips.)

in the latter.

All instruments in daily use should be periodically tested against standard instruments, and in this connection the ampère gauges, and the voltmeters designed by Lord Kelvin and manufactured by Messrs. Kelvin and James White, Limited, of Glasgow, should be mentioned here. The ampère gauges are of two patterns, the sector gauge and the S.R. (syphon recorder) type, the former of which may be used either for direct, or alternating currents, while the latter is made with a moving coil and can be used with direct currents only. In the sector ampère gauge the solenoid carries the whole current and is so proportioned as to take an overload of fifty per cent. for fifteen minutes without damage to the instrument. This form of instrument has an almost even division scale, it is unaffected by external magnetic fields, has no error due to changes of temperature, and in an alternating current a change in periodicity or alternating wave form has no effect upon the indications of the gauge.

The Syphon Recorder type of ampère meter, or as it is often called, the moving coil instrument, differs from the foregoing in that the current to be measured is passed through a shunt, which in ordinary cases may be fitted within six feet from it, a pair of light connections joining up the potential terminals of the shunt to the instrument terminals. The shunt can also be fixed at greater distances by the provision of special connections. This form is dead-beat in its action, and the scale is in equal divisions, but it has the disadvantage of being much more delicate in construction than the sector type of gauge, and it is also affected by changes of temperature, though the error from this source is exceedingly small.

The electrostatic voltmeters of Messrs. Kelvin and White, as shown in Fig. 190, have the great advantage of being equally accurate on either direct or alternating circuits. Being electrostatic, they use no current, are unaffected by magnetism, and are entirely free from error due to changes of temperature. In instruments of this class, the shortness of the scale and the difficulty of reading from a distance has been an objection, but these have now been overcome, and instruments for high voltages and scales ten inches long are supplied in vertical scale type.

Electrical instruments are constantly changing, and improvements are ever civilising old constructions out of existence. The electricity meter, illustrated in the first edition of this Handbook, is now no longer made, its place having been taken by the Wattmeter designed by Lord Kelvin and shown by Fig. 191.

These instruments are of the electro-dynamometer type, and graduated to read directly in watts, or they may if desired be marked to indicate kilowatts or horse-power. They are suited for use either on a direct or alternating current. In all these instruments the main or fixed coils are wound with copper ribbon and carry the whole current. The shunt or movable coils are arranged astatically on a light aluminium frame, to which the pointer is attached. In the dial pattern, the movable system is carried on knife edges, and in the vertical scale (V.S.) pattern it is suspended by a flat strip of phosphor bronze. The proportion of non-inductive resistance in the shunt circuit is very great, and the current through the shunt circuit does not exceed three one-hundredths of an ampère. The error introduced through self induction, even in low voltage instruments, is quite negligible. All wattmeters for circuits up to 600 volts have their shunt resistances fitted inside the case; those for high tension have separate resistances arranged in one or more boxes, and where it is found desirable on alternating circuits to keep high tension leads away from the wattmeter, it may be arranged to work with series and potential transformers, but where the highest degree of accuracy is to be attained, non-inductive resistances for the shunt circuits are recommended.

There are many problems in dealing with the applications of electricity requiring special study by the beginner. He should certainly understand the effect of introducing resistances into the circuit—the dissipation of voltage and its effect upon the current, and should further study the methods

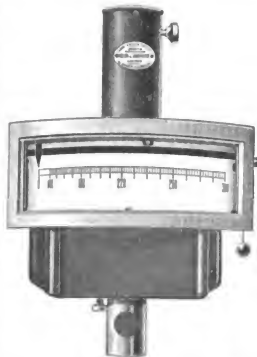


FIG. 190.—ELECTROSTATIC VOLTMETER.
(Messrs. Kelvin and White, Ltd.)

of generating alternating currents of high tension and transforming them into currents of low tension.* He should further be aware of the methods used to convert alternating currents into continuous currents.

Electro-Chemical Processes — We may now turn to those chemical processes in which electricity plays a part; but we must not be too strict in drawing the lines of our classification, as it is necessary to travel very near the borderland of metallurgy. There are several processes of this character that may now reckon to have become firmly established, such as the manufacture of aluminium, calcium carbide and potassium chlorate, but there are others that cannot yet be considered as having emerged from their trial. The most recently published financial statements of the companies engaged in the electrolysis of common salt do not show any advantage over the older chemical methods.

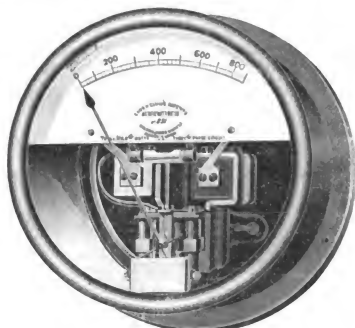


FIG. 191.—ENGINE-ROOM WATTMETER.
(Messrs. Kelvin and White, Ltd.)

The subject, so far as it concerns the Chemical Engineer, may be divided into four sections, viz. :—

- (1) The deposition of metals, whether from the point of view of winning them from their ores; for the purpose of refining them; or, for depositing them in definite industrial forms.
- (2) Electrolysis proper, when the chemical compound is resolved into its elements, or otherwise altered in composition.
- (3) Electro-smelting, as in the production of aluminium, steel, chromium, the various alloys of iron, and calcium carbide.
- (4) Electro-magnetic separation of minerals, as in the separation of iron ore from the silica or gangue in which it is embedded.

The work to be done in any of these sections admits of fairly exact computation, even before any practical work be entered upon, and in this

* Transformers, by Gilbert Kapp. London: Whittaker and Co. 1896.

direction Table 44 will be found useful. Reference will often be required to the heat of formation of various electrolytes, but as space cannot be found for such lengthy tables as these, the reader is referred to Dr. R. Biedermann's *Beilage z. Chemiker Kalender** for 1900, which contains this and all similar information in tabular form.

TABLE 44.

SHOWING THE ELECTRO-CHEMICAL CHARACTERS OF THE ELEMENTS.

Elements.		Atomic Weight.	Valency.	Equivalent Weight.	Grammes liberated per amp. hour.
Aluminium	Al.	27·04	3	9·01	0·3377
Antimony	Sb.	119·60	3	39·87	1·4940
Arsenic	As.	74·90	3	24·97	0·9360
Barium	Ba.	136·90	2	68·45	2·5660
Bismuth	Bi.	207·30	3	69·10	2·5900
Boron	B.	10·90	3	3·63	0·1360
Bromine	Br.	79·75	1	79·75	2·9890
Cadmium	Cd.	111·70	2	55·85	2·0930
Calcium	Ca.	39·91	2	19·95	0·7477
Chlorine	Cl.	35·37	1	35·37	1·326
Chromium	Cr.	52·40	3 and 2	26·20	0·9820
Cobalt	Co.	58·60	2 and 3	29·30	1·0980
Copper	Cu.	63·18	2	31·59	1·1840
Fluorine	F.	19·10	1	19·10	0·7159
Gold	Au.	196·70	3	65·57	2·4580
Hydrogen	H.	1·00	1	1·00	0·0375
Iodine	I.	126·54	1	126·54	4·7830
Iron	Fe.	55·88	2 and 3	27·94	1·0470
Lead	Pb.	206·40	2	103·20	3·8680
Lithium	Li.	7·01	1	7·01	0·2627
Magnesium	Mg.	24·30	2	12·15	0·4554
Manganese	Mn.	54·80	2 and 3	27·40	1·0270
Mercury	Hg.	199·80	2	99·90	3·7440
Nickel	Ni.	58·60	2 and 3	29·30	1·0980
Oxygen	O.	15·96	2	7·98	0·2990
Phosphorus	P.	30·96	3	10·32	0·3868
Platinum	Pt.	195·08	4	48·77	1·1828
Potassium	K.	39·03	1	39·03	1·4630
Silver	Ag.	107·66	1	107·66	4·0260
Sodium	Na.	23·00	1	23·00	0·8620
Thallium	Tl.	203·70	2	101·85	3·8174
Titanium	Ti.	48·00	4	12·00	0·4500
Tin	Sn.	118·80	2	59·40	2·2260
Zinc	Zn.	65·10	2	32·55	1·2200

The Deposition of Metals. — The electrolysis of binary compounds may be readily explained by reference to the decomposition of lead chloride in a concentrated aqueous solution in such a manner as to set free metallic lead and free chlorine. Lead chloride is not the best compound for a student to commence upon for a practical experiment, as the electrolysis

* Berlin: Julius Springer. London: H. Grevel & Co.

of this salt is complicated by certain secondary reactions, of which, beyond the bare mention of them, no notice need be taken here. The splitting up of lead chloride is merely taken to illustrate the principle of calculation when a metal is liberated on the one hand, and the haloid on the other.

Let us suppose we have a strong and hot solution of chloride of lead, from which it is desired to deposit the lead. On referring to Biedermann's Tables, it will be found that the heat of formation of lead chloride is 77.9 calories for 277.14 grammes of the chloride.

The molecular weight of lead is	206.40
Chlorine combined with lead is	70.74
	<hr/>
Molecular weight of lead chloride	277.14

Lead being a divalent element, the above molecular weight of its chloride requires to be divided by two to bring it down to the hydrogen equivalent, so that the minimum voltage required to decompose chloride of lead is

$$\frac{38.95}{23} = 1.69 \text{ volts,}$$

the denominator 23 being a constant for all electrolytes, based on the laws of Ohm and Joule.

Reference to Table 44 will show that each ampère hour of current will deposit 3.868 grammes of lead, so that if we wish to deposit ten pounds per hour (4,536 grms.), there will be required:—

$$\frac{4.536}{3.868} = 1.170 \text{ ampères of current.}$$

To turn this into "watts" and horse-power, the ampères must be multiplied into the volts, to produce "watts," which last divided by 746 gives the horse-power.

$$\frac{1.170 \times 1.69}{746} = 2.6 \text{ H.P., or } 1.98 \text{ kilowatts.}$$

The above is the actual work needed to overcome the force holding the atoms together in the molecule, but it by no means represents the total power required in actual practice, a fact that should be thoroughly understood.

In order to be able to calculate the horse-power required, with any degree of precision, we must know with certainty the resistance due to each part of the apparatus. Let us examine the subject, with the foregoing figures as an illustration.

The symbol E is used to indicate the total electromotive force of a dynamo in volts, but the potential at the terminals of every dynamo is always less than E , because part of the E.M.F. is employed in driving the current through the resistance of the armature. If E be the total electromotive force, then E' may be written for the difference of potential between the terminals of the dynamo, and if r is the resistance of the armature coils, and R the external resistance of the circuit, then

$$E = \frac{r + R}{R} E';$$

E represents the force delivered from the engine, while E' is that available for electrolysis, and is measured by the voltmeter.

Let us now suppose that only one electrolysing cell be employed with electrodes 10 centimetres apart, and working with a current density of 200 ampères per square metre. As we require 1,170 ampères, the total surface immersed will have to be $1,170 \div 200 = 5.85$ square metres. The resistance of the cell may be roughly computed as follows:—The specific resistance of a strong chloride of lead solution may be taken as 2.4 ohms. per cubic centimetre, or $2.4 \div 10,000 = 0.00024$ per square metre one centimetre in thickness, and as the electrodes are 10 centimetres apart, the resistance of the cell would be:—

$$\frac{0.00024 \times 10}{5.85} = 0.00041 \text{ ohm.}$$

If we have 100 yards of a cable composed of 260 strands of No. 11 (I.W.G.) wire it will have a resistance of 0.0007 ohm. The internal resistance of the dynamo will probably be about 0.006 ohm. In all we shall have:—

For the dynamo	.....	0.0060 ohm.
„ conductor	.....	0.0007 „
„ cell	.....	0.0004 „
Total resistance of the circuit		..... 0.0071 „

To this must be added the resistance due to the opposing E.M.F.:—

$$R = \frac{E}{C} = \frac{1.69}{1,170} = 0.0014 \text{ ohm,}$$

or in all $0.0071 + 0.0014 = 0.0085$ ohm. Then as $E = C R$,

$$E = 1,170 \times 0.0085 = 9.94 \text{ volts,}$$

practically 10 volts, so that

$$1,170 \times 10 = 11,700 \text{ watts,}$$

or in other words 11.7 kilowatts, or 15.7 H.P. would be required to deposit 10 lbs. of lead per hour from a solution of lead chloride when a single cell is employed.

To put this in another way, as foreshadowed on page 370:—

$$(C \times E) + C^2 R = \text{watts}$$

$$1,170 \times 1.69 + (1,170)^2 \times 0.0071$$

$$1,977 + 9,719 = 11,696$$

$$\text{and } 11,696 \div 746 = 15.7 \text{ H.P.}$$

It will no doubt be inferred by the student that a current of 11.7 ampères one hundred times repeated will deposit as much lead per hour as the comparatively large current of 1,170 ampères, already illustrated. This is so—and we may now inquire into the question of the power required in such a modification, viz., the passage of 11.7 ampères through 100 cells

in series. The resistance of the dynamo may be less, but we will assume it to be the same. The resistance of the conductor may remain the same as in the former case, but the new disposition of the electrolysing tanks completely alters the whole aspect of the question. As we have 100 tanks, the area of each electrode need be but the one hundredth of the area employed in the former case to establish the same current density, *i.e.*, each electrode should have an area of 0.0585 sq. metre, so that the resistance would be :—

$$\frac{0.00024 \times 10}{0.0585} = 0.041 \text{ ohms.}$$

As there are 100 tanks, the opposing E.M.F. of 1.69 volts will have to be overcome in each tank, or 169 volts in all. The resistance of each cell being 0.041 ohm, the resistance of the 100 cells is necessarily 4.1 ohms, so that :—

$$C \times (E_{100}) + C^2 \times (R \times 100) = \text{watts}$$

$$11.7 \times 169 + (11.7)^2 \times 4.1$$

$$1,977 + 561 = 2,538 \text{ watts}$$

$$\text{and } 2,538 \div 746 = 3.4 \text{ H.P.}$$

The metal deposited is the same in both cases ; in the first method, 15.7 H.P. are consumed, while in the second arrangement the amount is only 3.4 H.P. For the first installation, a dynamo would be required giving 1,170 ampères at 10 volts, while in the second mode of conducting the process, the dynamo would have to yield 11.7 ampères at 217 volts, or 2.17 volts as an average for each cell.

The case thus illustrated presupposes the insolubility of the anodes. If the anodes are soluble, as in the case of copper refining, or the refining of silver lead, the opposing E.M.F. is practically nil, and there are only the resistances of dynamo, conductor and cell to consider. These, however, are not small items, and perhaps will amount to more than half a volt per tank.

Tomassi, in a communication to the *Zeit. für Electro-Chemie*,* gives the details of a plant for depositing and desilvering lead, to the extent of 84 tons a day, in 500 tanks, worked in series, the current employed being 1,800 ampères at 382 volts. The anodes are slabs of silver lead 5 cm. in thickness, while the cathodes are circular discs 3 m. diameter, and arranged 2 cm. from the anodes. The average voltage for each bath is 0.72, and the length of the cable 500 metres, in which there is a drop of 6.3 volts. The total horse-power installed is 1,000, of which 980 goes to drive the dynamos, while 4 H.P. serves to rotate the cathodes, and 16 H.P. is employed for the compression of the lead sponge and for lighting the factory.

In copper refining, the electrolytic industry owes its success to the presence of so-called impurities in raw copper. Nearly all the raw copper made in the Western States of America contains silver and gold, and when such copper is electrolytically refined, the silver and gold form an insoluble "anode sludge" at the bottom of the tanks, from which the noble metals can be very simply recovered. It has been estimated that the gold and

* 1896-7, Nos. 14 and 15.

silver recovered by the Anaconda Copper Company, at their electrolytic works in Montana, amount to nearly three-quarters of a million sterling in the space of a year. The method of refining in use in all these electrolytic refining establishments is practically the same. The raw copper is cast into plates of a convenient size to form soluble anodes, generally 33 ins. long, by 24 ins. wide, and from 1 in. to $1\frac{1}{4}$ ins. thick, while the cathode is formed of thin sheets of pure copper, 33 ins. by 11 ins., weighing about a pound to the square foot, placed on each side of the anodes. When the current passes, the anode dissolves away, and is deposited upon the pure copper cathode. The solution in which the anode is suspended is one of copper sulphate, containing about 150 grammes of sulphuric acid to the litre, and 40 grammes of copper, and the impurities in the crude copper either remain in this solution or are deposited as a slimy mud of "anode sludge" already mentioned. The deposited copper is usually of a coarse crystalline character, owing to the high current density employed in electrolysing, and it is always re-melted, and finds its way into commerce as ingots. The anode-sludge necessarily varies much in its composition, containing from 15,000 to 18,000 ozs. of silver per ton, and from 35 ozs. to 100 ozs. of gold.

In this connection it may be mentioned that the current density has much to do with the character of the metallic deposit, especially in depositing copper. Two hundred ampères per square metre for the best work is perhaps the rate most generally followed, the electrotype plates for the Ordnance Survey being even less than this, or about 120 amperes per square metre per hour. When a coarse crystalline deposit is required for metallurgical purposes, as much as 700 to 1,000 ampères per square metre may be employed. At the Great Falls electrolytic copper refinery in the Montana region of the United States, 400 ampères are circulated per square metre of cathode surface, when working up converter anodes, which is equal approximately to 40 ampères per square foot. At the Anaconda refinery, only 100 ampères per square metre are employed, or 10 ampères per square foot. The difference in potential per tank is 0.3 volt when soluble anodes are employed, and about 2.0 volts when working with insoluble anodes. Zinc may be deposited with a current density of 30 to 50 ampères per square metre, at which it yields a hard, dense deposit, but in the Hoepfner process, in which the zinc is re-melted, a current density of 100 ampères per square metre is employed. Silver requires 16 to 40 amperes; gold, 8 to 16; but in all these operations the quality and strength of the solutions, as well as the resistance between the anodes, are points of great moment.

The Hoepfner process for the deposition of metallic zinc has been tried at Fülhrfort-sur-hahn, and at Northwich, in Cheshire, and though it cannot be described as a successful financial operation, yet it is the best so far as the electrodeposition of zinc is concerned. The chemical part of the operation presents no great difficulties, as all details are now thoroughly understood. The raw material is the calcined product from local pyrites (chalcopyrites and blende). This is roasted with salt, and the product lixiviated, the sulphate of soda being crystallised out at -5°C . The mother liquors consist mainly of zinc and sodium chlorides, together with salts of iron and

other impurities which are eliminated by treatment with bleaching powder and carbonate of lime, and the copper, nearly always present, is precipitated with metallic zinc. The solution finally obtained is composed approximately of 20 per cent. of ZnCl_2 and 22 per cent. of common salt, and this is subjected to electrolysis.

The electrolyzers are furnished with nitro-cellulose diaphragms, the cathodes being formed of rotating discs of zinc. The solution enters the tanks with about 8 per cent. of soluble zinc, and leaves with not less than 2 per cent. It has been found by experience that if the zinc contents be worked down below this latter figure that the metal is not dense enough, even at 100 ampères per square metre.

The zinc obtained by this process is very pure, assaying 99.98 per cent. of the pure metal, with but traces of iron, lead and thallium, but as worked it could only compete successfully where a specially pure article was demanded. The difficulties lie chiefly in the electrical operations, and are caused by the presence of impurities, notably the iron oxide.

Copper tubes and other commercial articles are now made by electrolytic processes, though what advantages such methods possess over purely metallurgical operations is not as yet very clearly demonstrated. The crystalline character of the deposits produced by electrolysis introduced greater difficulties than had been imagined, but to a large extent these have been overcome, and sheets measuring 12 ft. \times 4 ft. are at present being made in Widnes by the Dumoulin process, and are stated to be perfectly satisfactory. The Electrical Copper Company, of Widnes, who work this process, deposit the copper upon revolving mandrils, 12 ft. long and 16 ins. diameter, working in a series of 30 electrolysing tanks. When the deposit has reached a thickness of one-sixteenth of an inch, the tubes are removed from the mandril and slit up from end to end, thus making a sheet 4 ft. \times 12 ft. of very satisfactory quality, so far as regards density and strength.

Electrolysis Proper. — The system of preparing chlorine by the electrolysis of soluble chlorides was described in 1851 by Charles Watt in his specification of September 25th of that year, numbered 13,755. The salt to be decomposed was placed in a vessel divided into two or more compartments by means of porous partitions, the vessel being furnished with electrodes and provided with a movable head for collecting and conveying away the gases generated. The electric current required was generated by a Daniell battery of six cells, the temperature of the electrolysing bath being maintained at not less than 40 C., and the strength of the solution being kept up by adding from time to time fresh portions of the same kind of salt as that undergoing decomposition. The specification goes on to say that if the chlorides of potassium or sodium are acted upon, caustic potash or soda is produced, and if the carbonates are required in place of the hydrates a current of carbonic acid gas must be passed into the compartments containing the eliminated alkali. A second section of the specification relates to the conversion of the chlorides of the alkalies and alkaline earths into the hypochlorites or chlorates of those bases, and the method described is specially noted as being applicable for preparing a bath for bleaching purposes.

It will of course be seen that the principle of the aforesaid patent of Charles Watt clearly anticipates the large number of processes for the electrolysis of alkaline chlorides that have appeared since the year 1880. The principle is there, and the monopoly granted by the State (subject to its being subsequently found valid in a court of law) relates only to the improvements made in the method of carrying out the principles in practice. The decomposing cell, the porous partition, the electrodes, the hood for carrying away the gases, are all to be found in Charles Watt's specification. And when we come to consider the products, Watt aimed at producing the hydrates of potash and soda, but he also provided for the conversion of the hydrate into carbonate in a similar manner to that now carried out in the Hargreaves-Bird process. Watt also claimed the electrolytic production of chlorates and of hypochlorites or bleaching solutions.

It may be asked why (in the face of the process of electrolysis being so well understood by Watt in 1851) so long a delay occurred in utilising the invention? It was due entirely to the want of a cheap source of electricity, and it was not until after the introduction of the Gramme dynamo machine in 1871 that industrial electrolysis became financially possible. The introduction of practical electrolysis, although attempted by many between 1871 and 1884 could not by any means be styled successful, but a distinct advance was made by Hermite in 1884 by the production of an apparatus for electrolysing soluble chlorides and preparing bleaching liquids, in situations where ordinary bleaching powder was an expensive article, and the various patents that have been taken out between that date and the present time for these operations show that many difficulties have arisen in practice.

At the Ely Paper Mills at Cardiff the Hermite process was installed in 1889, and the plant consisted of one steam-engine of 190 H.P., three dynamos of 1,000 ampères each, running 38 volts, and twenty electrolysing tanks, each of which yielded chlorine solution equal to 100 kilos. of bleaching powder per 24 hours, or roughly, a total of two tons of bleach per day. The electrodes were of zinc and platinum, the zincs revolving between brushes to keep them free from the magnesium hydrate that constantly deposited upon them. In this process, the entire separation of the magnesium from the chlorine was not aimed at. The object was to split up the MgCl_2 molecule, and to re-combine the products in the presence of water as MgOCl_2 which was used as a bleaching agent, during which it became reduced to MgCl_2 again. This was again electrolysed to form MgOCl_2 and used over again and again.

The process as described was run for several months, but the cost of bleaching paper-pulp by its use exceeded by four times the cost of bleaching with chemically prepared bleaching powder, and so the electrolytic process was abandoned. Chloride of magnesium proved too costly to throw away after once using, and by employing it more than once, it was found that the chlorine liberated at the anodes first attacked the soluble organic matters in the solution which became more concentrated with each journey round.

The foregoing process, however, serves as an example of one of the main divisions in electrolysis. It has often been stated that the decomposition of fused salts is more economical than that of solutions, when electricity is the decomposing agent. With such salts as lead chloride, where metallic lead could be simply run in pigs from the electrolyser, this might be the case, though even this is doubtful, but with such salts as magnesium chloride, in which the metal could not be gathered and utilised in quantity, even if the chemical conditions allowed of it, the electrolysis of the fused salt is out of the question as a source of chlorine.

Although the equation $\text{MgCl}_2 = \text{Mg} + \text{Cl}_2$ represents what would take place in a perfect operation of electrolysis in fusion, it does not express the process that takes place in an ordinary aqueous solution, which is $\text{MgCl}_2 + 2\text{H}_2\text{O} = \text{MgH}_2\text{O}_2 + \text{Cl}_2 + \text{H}_2$, the gases appearing at the electrodes and not the metal. In the case of the fused salt, the voltage required to overcome the chemical affinity is

$$E = \frac{75.6}{23} = 3.29 \text{ volts,}$$

while when the strong aqueous solution is electrolysed as indicated in the second equation the theoretical voltage is less than 2.0, the practical proof of this being that one single Bunsen cell will decompose it.

$\text{MgCl}_2\text{H}_2\text{O}_2 + \text{H}_2\text{O} = \text{MgH}_2\text{O}_2 + \text{Cl}_2 + \text{H}_2$
 (151.2 + 69) — 148.8
 = 71.4 calories for the molecule of MgCl_2 , or 35.7 calories on its hydrogen equivalent, the electrolysis in the wet way therefore requires

$$E = \frac{35.7}{23} = 1.55 \text{ volts,}$$

or less than half the horse-power for the same weight treated by the fusion method.

The same reasoning applies to the electrolysis of common salt. In the fused state without any further complications sodium chloride should require to decompose it—

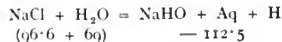
$$E = \frac{96.6}{23} = 4.2 \text{ volts,}$$

but when the liberated sodium is absorbed by a lead or mercury cathode the voltage required would be

$$E = \frac{96.6 - 19.1}{23} = 3.37 \text{ volts,}$$

96.6 being the heat of formation of common salt and 19.1 the formation heat of mercury amalgam, NaHg_8 .

Let us now consider the force necessary to decompose common salt in solution.



so that the voltage required is at least :—

$$E = \frac{96.6 + 69 - 112.5}{23} = 2.31 \text{ volts.}$$

It must be made clear that the foregoing voltages are only those theoretically necessary to overcome the force of chemical affinity; the actual E.M.F. required in practice is always much larger owing to the various resistances in the circuit. We have seen that in the wet way 2·31 volts only are required for the purely chemical work, yet in the Hargreaves-Bird process, as seen by the author on several occasions, the voltmeter usually indicated over 4 volts. Again, the Castner-Kellner process when at work at Oldbury in its experimental days, drove 1,100 ampères at 60 volts through two rows of 14 cells each, filled with brine at 40° Tw., which is 4·3 volts per cell, while the chemical work only requires 3·3 volts.

In the Hermite process practically five volts were consumed in the electrolyzers, partly on account of the adherence of the magnesium hydrate to the zinc cathodes (thus seriously increasing the resistance), and partly on account of the dilution of the solution which caused it to conduct badly, thus raising the voltage required from 1·55 units.

One factor in the electrolysis of aqueous solutions must not be neglected, and that is the various secondary decompositions that are likely to take place. In the electrolysis of brine there is generally a considerable decomposition of water by the current, with the result that oxygen is set free in the cell, producing hypochlorites, chlorites, chlorates and perchlorates, hydrogen being evolved which may mix with the chlorine. In the Castner-Kellner process as now worked (1904), notable quantities of hydrogen pass over into the bleaching powder chambers with the chlorine, so much so that the chambers are not provided with the usual glass windows seen in all other chambers working with chemical chlorine.

Some few years ago (1893), the author was desired to investigate a new process which included the electrolysis of salt solution, and he thereby had an opportunity of investigating the extent to which these secondary decompositions took place. In one experiment a current of 40 ampères at five volts was passed through 26 litres of brine, the electrodes being separated by a porous diaphragm, and the current density being 100 ampères per square metre. After passing the current for eleven hours, the anode solution being kept strong with solid salt, the solution contained the following impurities in grammes per litre :—

	Grammes.
Chlorine capable of being displaced by an air current	0·80
Chlorine as chlorites and hypochlorites	1·06
Acidity as HCl.	0·35
Sodium chlorate	0·67
Sodium perchlorate	1·14

It was also found during these experiments that if a greater current density than 100 ampères per square metre was employed the life of the porous diaphragm was very short, but so long as this current density was not exceeded, the renewals did not appear to be a serious item. In the Hargreaves-Bird process the current density employed is 230 ampères per square metre, and it is stated that these diaphragms will sometimes run for thirteen weeks before requiring renewal.

The four main processes now in actual operation for the electrolysis of salt are, (1) electrolysis without diaphragms, but with an absorbing metallic cathode, as in the Castner-Kellner processes; (2) electrolysis with diaphragms as practised by the Electrolytic Alkali Company at Middlewich, known as the Hargreaves-Bird process; (3) gravity cells, dispensing with both porous diaphragms and mercury; and (4) electrolysis in fusion as in the Acker process. The costs and working details of these processes have not as yet been made public in any way, though Kershaw, in a series of articles in the *Electrician*,* gives the summary shown in Table 45.

Although so little has been published of a reliable nature with reference to the financial results of the practical electrolysis of alkaline chlorides, there has been enough made public to preach caution to the investor, to show the user of chlorine bleaching products the necessity of thoroughly investigating the merits of all new processes offered to him, and to teach the student that perfection has by no means been arrived at yet.

The technical success of the mercury cathode process of electrolysis can only be judged by the balance sheets of the operating companies. Rhodin, however, has given some details of the construction and working of his process, which it may be useful to quote here. He says:—The process employed at Sault Ste. Marie is what is known as a mercury cathode process. The electrolytic cell itself is a circular vessel of vitrified earthenware, the lower surface having a number of depending openings, and the top surface also has openings corresponding to those on the bottom surface. The appearance of the cell resembles that of a wheel, the openings above referred to corresponding to the spaces between the spokes. With a view of strengthening the resemblance mentioned, it will have to be supposed that the width of the spokes of a wheel be equal to the distance between them. The anodes consist of carbon blocks, which fit into the openings of the top surface of the electrolytic cell. Into these carbon blocks there are fitted, by means of a screw thread combination, a number of carbon rods, hanging downwards into the openings of the bottom surface of the cell. It will be understood that when these anodes are placed in position, the top surface of the cell is closed and, of course, made tight by means of a special cement. This electrolytic cell is suspended inside a shallow cast-iron dish, the diameter of which is 5 ft. The bottom of this cast-iron vessel is covered with a layer of mercury, which seals the interior of the electrolytic cell from the annular space of the cast-iron vessel surrounding the cell itself. The cell is suspended by means of a vitrified earthenware pipe, bolted to a circular flange, of the same diameter as the pipe, in the centre of the top surface of the cell. When the electrolytic cell is in operation it is, of course, filled with brine, whilst the annular space of the cast-iron vessel is filled with water, the mercury on the bottom of the cast-iron vessel forming a seal between the brine and the water, and preventing communication between these liquids. The carbon anodes are connected up to a metallic ring contact, and this is connected to the positive pole of a dynamo, whilst the cast-iron vessel

* The *Electrician*, Nov.-Dec., 1902.

TABLE 45.
CURRENT ENERGY EFFICIENCIES AND COST OF POWER OF THE VARIOUS ELECTROLYTIC ALKALI PROCESSES.
AFTER KERSHAW.

PROCESS:	E.M.F. required in volts.	Actual yield in grammes.				Efficiencies per cent.		Per metric ton of caustic soda.	
		Per amp. hour.		Per kw. hour.		Current.	Energy.	Kw. hours.	Cost.
		NaOH	Cl.	NaOH.	Cl.				
<i>Wet Processes.</i>									
Castner-Kellner	4.0	1.363	1.136	340	284	91	52.3	2735	£ s. d. 2 17 0
Hargreaves-Bird ..	3.4	1.196	1.057	351	310	80	54	2649	2 15 2
Rhodin	5.0	1.349	—	269	—	90.2	41.4	3457	3 12 0
Aussig "Bell"	4.9	1.308	—	266	—	87.5	40.9	3496	3 12 10
Theoretical figures ..	2.3	1.495	1.322	650	574	100	100	—	—
<i>Fusion Process.</i>									
Acker	7.0	1.370	—	195	—	91.6	54.9	4769	4 19 4
Theoretical figures ..	4.2	1.495	1.322	356	314	100	100	—	—

is connected to the negative pole. When the current is on, the electrolytic cell itself is being rotated inside the cast-iron vessel, the brine is being decomposed, the chlorine going off at the surface of the brine through the pipe by means of which the cell is suspended, and the sodium depositing on the mercury inside each opening of the bottom surface of the cell. The mercury, by reason of the rotation of the cell, and through the depending flanges dipping into it, is being put into motion towards the periphery of the cast-iron vessel, a motion greatly accelerated by radial ribs placed on the bottom of the cast-iron dish. It will consequently be seen that the mercury, after having received a certain quantity of sodium, and having amalgamated with it inside the openings of the electrolytic cell above referred to, is being continuously thrown out into the annular space of the cast-iron dish which contains water, with which the sodium contained in the mercury amalgam reacts, forming sodium hydrate and hydrogen. The very essence of a mercury cathode cell is to remove the mercury amalgam from the actual field of decomposition as soon as it is formed, afterwards to extract the sodium from the amalgam, and again to have the mercury ready to amalgamate with more sodium.

The factory, erected at Sault Ste. Marie, Ontario, by The Canadian Electro-Chemical Co., Ltd., has a power installation of 660 kilowatts, consisting of three 220 kilowatt dynamos, each driven by a separate water wheel. The electrolytic installation consists of 120 cells, through which a current of from 800—1,000 ampères per cell is used, with a difference in potential of from 4 to 5 volts, and the passing of this current through a cell that is only 3 ft. in diameter has only been made possible by the discovery of the Acheson graphitised carbon electrode, the conductivity of which is four times as great as that of ordinary carbon, and also by the system of the circulation of the electrolyte employed, whereby a concentrated solution of salt is always present in the actual field of decomposition.

It is often held that in using a mercury cathode process for the decomposition of brine, that there must be a loss of mercury, and that such loss must be a very serious matter, owing to the great value of the metal. As may be deduced from the description of the electrolytic cell given above, the chance of the mechanical loss of mercury is very slight, owing to the construction of the cell. The mercury is covered with a liquid throughout, and the hydrogen, given off in the combining chamber, is not given off from the mercury surface, so that the hydrogen going into the atmosphere in the cell room carries no mercury. Regarding the solubility of the mercury, in the sodium hydrate solution, Rhodin states that it might be interesting to know that it has been found, as a result of careful research on the subject, that one pound of mercury is dissolved by the alkali solution for every 27,500 lbs. of caustic soda produced. The electrolyte, on account of its contents of free chlorine, always carries mercury to the extent of 5/100ths of 1 per cent. of its contents of salt. The electrolyte in the circulation system is changed once every four to six weeks. The loss of mercury resulting thereby amounts to approximately 20 lbs. in the period of time stated.

In the Hargreaves-Bird process, the cells are built up of strong cast-iron plates, 10 ft. long, 5 ft. high, and are $2\frac{1}{2}$ ft. in width over all, the internal width of the anode chamber being 15 ins. The form is thus a long narrow and deep box, divided longitudinally into three compartments, the wide anode chamber in the centre and the two cathode chambers, one on either side of it. The anode chamber is separated from the cathode chamber by a porous partition about one-tenth of an inch in thickness, made of cement and flock asbestos, and is pickled before use in a solution of silicate of soda. The cathode itself is constructed of a large mat of copper wire of one-sixth of an inch mesh, the wires measuring about one-twelfth of an inch in diameter. This mat is rolled flat after manufacture, so as to better support the asbestos diaphragm which during work is under considerable hydrostatic pressure. The cathode chamber remains practically empty during the working of the cell, the electrolysed ion being carbonated by the carbonic acid gas present, and washed from the surface of the asbestos partition by means of saturated steam.

Within the anode chamber are five vertical rods to which the anodes are fixed, a copper core being connected with the copper conductors and copper strips above; the core is embedded in cement, upon which irregular lumps of gas-retort carbon are bolted on both front and back. These lumps are in their natural rough state about 12 ins. long by 6 ins. broad and 1 in. thick. The bolts are protected by means of cement and oil, and generally last as long as the anodes themselves, which is about a couple of months. The diaphragms will last on an average from 70 to 80 days, but in actual practice it has been found advisable to renew them after a run of 70 days. The electrical connections are effected by means of copper strips, and at the works at Middlewich 56 cells are arranged in four lines of 14 cells each, a current of 60 volts being passed through the 14 in series, so that each cell requires nearly 4.5 volts.

There is no circulation from cell to cell. The brine of 1.20 sp. gr. is fed separately into each, and the electrolysis is continued until the liquor has become too impure for further use, when it is changed, and at this point it is found that fully two-thirds of the chloride has been utilised. The brine enters the anode chamber by an unglazed earthenware pipe which has been boiled in gas-tar. It is fixed at one end of the chamber, and reaches nearly to the bottom of the cell, while there is a luted overflow pipe at the other end of the chamber. Each cell holds about 300 gallons of brine. The chlorine gas evolved during the passage of the current is taken off from the cells by a system of earthenware pipes, being drawn forward by an exhausting fan made of earthenware and passed on to the bleaching powder chambers under a slight pressure, while the solution of carbonate of soda runs from both cathode chambers in a continuous stream, into a tank placed to receive it. The strength of this solution is about 150 grammes of carbonate per litre, or, roughly, about 9 lbs. per cubic foot.

The actual power plant as seen by the author in 1902 consisted of two horizontal Robey engines, each of 480 horse-power, driving by means of ropes two continuous current six-pole dynamos, and producing a current

of 2,200 ampères. It has already been noted in Vol. I. that the brine necessary for use in the foregoing works is raised by the Pohlé air lift system from a 10-inch pipe, with a central air pipe 3 ins. diameter. The cost of pumping is said to be threepence per 1,000 gallons, but in this connection Table 19, page 227, may be consulted with advantage.

The gravity electrolytic cell, mentioned in the classification on page 394, is one upon which many hopes have been raised. No reliable figures of large scale working are available, but the advantages of the system lie in being able to dispense both with the mercury cathode and the porous partition—points of no small advantage; and, therefore, the subject needs further research to inquire into the advantages and disadvantages of the system.

The fourth class of operations under this classification comprises the electrolysis of anhydrous salts in a state of igneous fusion. Lead chloride is one of the materials that has been operated on, and for a time the process seemed commercially possible, though it seems to have passed to the limbo of forgotten things. Lead chloride fuses at 485°C. , and the latent heat of fusion is $20\cdot90$ c.h. units for each pound of substance, while metallic lead fuses at 325°C. and the latent heat of fusion is $5\cdot86$ c.h. units. It would thus seem that lead chloride is eminently suitable for electrolysis in fusion, if other conditions did not conspire to make the operation expensive. Unfortunately, chlorine at high temperatures is very corrosive, attacking the carbon electrodes with avidity, forming amongst other things chloro-compounds of the benzene series. This destructive action militates against all fusion processes; and it remains to be seen whether it can be overcome.

An early fusion process was the Vautin, of which now the less said the better. It was projected to yield chlorine and an alloy of lead and sodium, but although considerable sums were spent upon it, in a works near Bolton, not a single pound of any commercial product was obtained for sale. The Acker process is a fusion method somewhat on the lines of the Vautin; fused common salt is electrolysed over a layer of melted lead, which acts as the cathode; chlorine is evolved while the lead-sodium alloy is continuously withdrawn from the cell, and decomposed with a current of steam. Though the difficulties incidental to the electrolysis of fused salt, at the high temperatures necessarily demanded, may not be unsurmountable, the very great depreciation and the rapid tear and wear will certainly have to be taken into account, and it may probably be found in the long run that the cost of evaporation of a dilute solution of caustic soda is not nearly so great as the losses by tear and wear and the frequent stoppages of the cell furnaces which must inevitably take place. According to Kershaw,* the Acker works at Niagara is utilising 3,250 H.P. in 45 separate fusion cells, each taking a current of 8,000 ampères at 7 volts, so that in course of time a definite pronouncement as to the feasibility of the process or otherwise may be expected.

The author refrains from reproducing any of the illustrations of the plant supposed to be in operation at the several works producing alkali and chlorine by electrolytic processes. Many of these are obviously copies of the

* *The Electrician*. Dec. 12, 1902, p. 306.

illustrations from patent specifications and by no means represent the latest developments, which are practically kept secret, but the principles upon which successful plants may be constructed, leaving cost outside the question, are all to be found in the foregoing portion of this chapter.

Before concluding the remarks upon electrolysis proper, some mention should be made of the perennial processes for the preparation of bleaching liquids. Each year produces a fresh crop, and many of the inventors seem to be in ignorance of what has been done before their advent. The master-patent was that of Charles Watt in 1851, so that the validity of the patents must depend entirely on the form and construction of the apparatus. It will at once be seen that if the current separates the two ions, chlorine and sodium, in presence of water, the sodium will finally appear as sodium hydrate (caustic soda), and that if the chlorine is brought into contact with the alkaline product, a hypochlorite will result. There may be a thousand

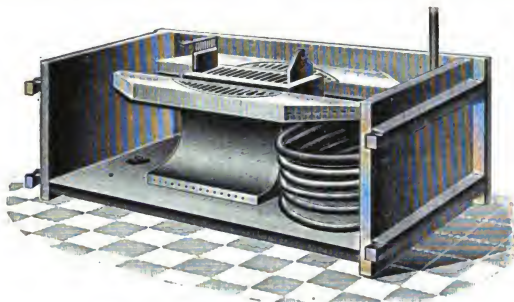


FIG. 192.—THE HAAS & OETTEL ELECTROLYSER.

and one ways of effecting this simple operation. some obviously better than others, and needing no special invention, but in all such processes the problem really resolves itself into one of the preparation of chlorine gas. Whether this can be effected in any cheaper manner than by the Deacon-Hasenclever process, or the manganese regeneration process, depends upon many local and economic conditions, which certainly should not concern us at this place, although it may deeply interest the user of bleaching compounds. These local conditions form a study in themselves.

One of the best appliances devised for converting common salt into sodium hypochlorite for bleaching purposes is the apparatus of Haas and Oettel shown by Fig. 192, and a study of this appliance will bring out many features of plants devised for the above purpose not generally considered. The illustration shows a slate tank containing a solution of brine in which is placed the electrolysing apparatus proper. This is specially constructed to insure a continuous circulation of the electrolyte, brought about by natural

means. The cell, constructed of non-conducting material, is furnished with a system of grooves in which slide a number of carbon plates, which act as double-pole electrodes. By this means an ordinary lighting supply of electricity, say, at 110 volts, may be used for the decomposition, without the intervention of any other appliance, the number of plates being proportioned to the voltage of the current. The walls of the cell are traversed by a series of tubular channels near the base, which penetrate to the base of the cell internally, the brine thus having free access. When the cell is at work, the gases evolved pass upwards through the brine solution between the electrodes, and so set up a circulation, as the liquid in the cell rises and overflows by a series of channels formed in the top walls of the cell, finding its way eventually into the brine tank surrounding it. Thus an effective circulation is maintained for the whole of the time the current is flowing. During the operation of producing a hypochlorite a moderately low temperature must be maintained. The method of circulation adopted generally secures this without further aid, but in order to insure that the temperature does not rise unduly, a coil of lead pipe, through which cold water is circulated, can be introduced, as shown in the illustration. Some experiments upon the working of this cell have been published, which the author has every reason to believe are trustworthy. They represent the hourly results of electrolysing a solution of 286 lbs. of salt in 166 gallons of water with a current of 50 amperes at 110 volts, and are shown in Table 46.

TABLE 46.

SHOWING THE WORKING OF THE HAAS AND OETTEL ELECTROLYTIC CELL.

Hours worked.	Grammes Chlorine per litre.	Total lbs. Chlorine produced.	Kilowatts employed.	Lbs. Salt per lbs. Chlorine.	% Salt decomposed	Lbs. Chlorine per kilowatt.
1	2.61	4.30	6.050	130	2.7	0.710
2	4.35	6.17	12.100	77	3.9	0.510
3	5.85	9.65	17.820	57	6.1	0.541
4	7.38	12.18	23.320	44	7.9	0.522
5	8.61	14.20	28.600	37	9.1	0.496
6	9.90	16.33	33.660	33	10.4	0.485
7	10.98	18.11	39.710	28	11.6	0.456
8	12.42	20.49	45.430	26	13.1	0.451
9	13.35	22.00	50.710	24	14.1	0.434
10	14.31	23.61	55.880	22	15.1	0.422
11	15.15	25.00	60.830	21	16.0	0.411
12	16.20	26.73	55.560	20	17.1	0.408

The two last columns of the table are instructive, as they show clearly that as the percentage of the salt decomposed increases, so the efficiency of the current decreases, this being due to secondary decompositions. It will be seen that the process goes on normally for about five hours, or until 10 per cent. of the salt has been decomposed, at which point the liquid contains

about 9.0 grammes per litre (or 9 ozs. per cb. ft.) of active chlorine. At this point, a change occurs and the kilowatt curve crosses the chlorine curve and continues to diverge from it, showing that, as time goes on, the efficiency of the current is continually decreasing. The cost of hypochlorite made in this way may be readily calculated when we know the cost of one kilowatt current. The British agents for the Haas and Oettel patents have calculated the cost of hypochlorite equal to bleaching powder on the basis of 0.22 penny per horse-power hour, but such a figure is evidently inadmissible. It has already been shown (page 373) that the actual cost per kilowatt of current actually exceeds one penny when generated by steam power in large units, and under the most favourable conditions, so that it is not likely that small users who generate their own current from a small high pressure non-condensing steam engine will obtain any better results. The author has before him while writing, a letter from the manager of a large Continental electro-chemical works, in which the following statement occurs:—"In all estimates we have seen of the cost of making caustic soda, or carbonate of soda and bleach by electrolysis in England, the cost of generating the electric current has been grossly under-estimated, and in no instance have the results of practical working been adduced." If then we put down the cost of current at one penny per unit (one kilowatt), and taking the figures of Table 46, we shall find that 26.73 lbs. of chlorine, or 74 lbs. of bleaching powder would cost about 66 pence or 5s. 6d. for current alone, to which the cost for salt, and other sundry charges, would have to be added. This cost for power alone reckons out to £8. 5s. per ton, from which the cost for current may easily be reckoned out for any other figure. As already stated, local conditions form a study in themselves. All the foregoing costs and conclusions may be altered where water power is cheap, say, as it is in certain districts of Sweden, where tank steamers could be sent right to the electro-chemical works and loaded for export exactly as petroleum is now carried. At one works in Sweden, known to the author, the water power does not cost more than £2 per horse-power per annum, all costs included, so that if the figures shown in Table 46 can be realised in continuous practice, the cost of current per ton of bleaching powder would be less than thirteen shillings.

Before concluding the remarks upon electrolysis, mention must be made of the production of chlorate of potash by electricity, an industry that has assumed very large proportions. The works of MM. Corbin & Co., located on the river Arne, which flows from the glaciers of Mont Blanc, are driven by twelve turbines, each of 1,000 H.P. The water is taken from the river and used under a head of 450 feet, and the power produced is enough to drive twelve dynamos, or sufficient to produce 400 tons of chlorate of potash annually. In addition to this work, there are ten others producing chlorates by electrolysis in various parts of the world. In the electrolytic production of chlorates conditions obtain which the maker of chlorine and alkali desire to avoid. As there is no need of a diaphragm in the cell a very much larger current density is allowable than in the case where the separation of the two elements is aimed at, and the temperature rises in consequence to

near 60°C . Then again, there is a higher internal resistance to overcome, as the solution of the electrolyte is much weaker than when brine is electrolysed for alkali making. The actual reactions taking place in the chlorate cell are still involved in doubt.

Electrical Smelting.—A few pages may now be devoted to the process of electro-smelting, and here again nothing but a rough outline can be attempted, as, outside of the aluminium, the calcium carbide, and several minor industries, the subject is still either in its infancy or in the experimental stage.

The ordinary electric furnace is simplicity itself. It may be described as a brick box holding the two poles or electrodes, and containing the charge to be smelted. The details must of course be adapted to the object

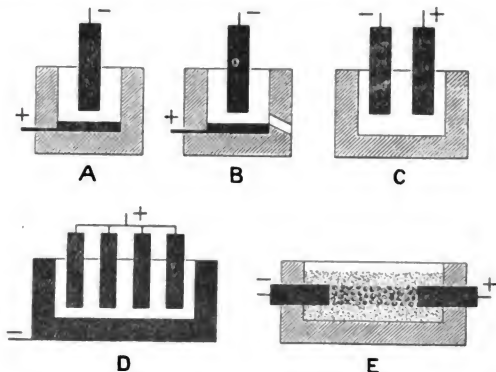


FIG. 193 - PRINCIPAL TYPES OF ELECTRICAL FURNACES.

in view, that is to say, there should be means for charging the furnace in a systematic manner, means for preventing the admission of air, and for allowing of the escape of gaseous products. There must also be means provided for the extraction of the fused product, and for the outflow of slag, whenever slag is produced in the operation. A very interesting and instructive paper upon "High Temperature Electro-Chemistry" was read by Messrs. Hutton and Petavel before the Manchester Section of the Institution of Electrical Engineers in November, 1902, to which the reader is referred, as it gives a very clear description of an experimental equipment and sets forth the principles upon which the operations depend. The principal types of furnace were illustrated in that paper as follows:—

A represents the ordinary pot furnace in which the current passes between a movable carbon electrode and a carbon or other plate forming

the base of the furnace. B is an example of a tapping furnace, being otherwise very similar to A. C in this case the furnace proper is formed of insulating material (generally lined with the unacted-on mixture), the current passing between the two carbons. D represents electrolytic furnaces such as are used for aluminium, zinc, etc., the current passes from one or several carbon electrodes forming the positive electrode to the negative pole, which is formed by the lining of the furnace. E resistance furnace; most frequently provided with a core through which the current is passed, and thus the surrounding material is heated. All the types except D are suitable either for alternating or direct current, the former being most frequently in use.

In actual practice, the electric furnace process is simply a carbon reduction at extremely high temperatures, with the simultaneous production of carbon monoxide, which in most cases can be utilised for further heating, or preparing the raw material for electric fusion. Thus in the preparation of phosphorus, from calcium triphosphate and silica, a silicate of lime is formed, while phosphorus vapour and carbon monoxide are liberated. The silicate of lime forms a fluid slag which continually runs away from the furnace in the same manner as iron slags leave the blast furnace. In the manufacture of calcium carbide there is no need for a slag outlet, as the whole product of the furnace is "carbide," which, however, is removed in several special ways. These two illustrations will serve to show the directions in which the ordinary furnace may be modified in construction without sacrificing efficiency.

It has already been stated that the furnace itself is but a brick box holding the electrodes, and containing the charge to be reduced and fused; but a little reflection will show us that the selection of the bricks must be an all-important matter. The temperature of the electric furnace has been the subject of much debate, but there is no doubt that it may be fixed at about $3,500^{\circ}\text{C}$. or about $6,300^{\circ}\text{F}$., so that anyone who has had experience with an ordinary gas furnace, working with 18 per cent. of carbonic acid in the exit gases, and working with a regenerator, will at once understand that the proper selection of the material is no slight matter. Ordinary fire-bricks will run like treacle in a temperature of $2,000^{\circ}\text{C}$., but magnesia bricks have a much more lasting disposition. Carbon blocks, made of powdered coke agglomerated with tar, or linings made of the same materials and pressed hard, are largely employed in connection with these furnaces, in which the wear and tear is exceedingly heavy.

A furnace largely employed on the Continent for calcium carbide making is known as the Rathenau furnace, and amongst other places is worked at Bitterfeld, with turbines driven by the falls of Rheinfelden. The construction of this furnace may be seen on reference to Fig. 194, which shows the general principles underlying all furnaces of this character.

The Rathenau furnace consists of a fire-brick body well bound together by iron bracings, a thick carbon block resting upon an iron plate which forms one of the poles of the installation. The furnace is closed by a carbon plate, through which is passed the upper carbon pole, which is insulated from it. At one side of the covering block is a sliding damper, which opens or closes the

lower aperture of the shute through which the raw material is fed. The raw material falls into the furnace on the sliding plate being withdrawn, and this is done gradually and at intervals, so that the temperature of the furnace is not unduly lowered at any time. When the molten carbide is ready for running off, the supply of raw materials is stopped, and the charge tapped through the hole at the base. Fresh raw material is then very gradually added by partially opening the shute damper, and the supply is continued until the molten charge has accumulated sufficiently to be tapped again. The access of air has, of course, a very destructive action on the substance of the electrodes, whereas, when all air is excluded, the loss of the electrodes is simply limited to the action of the arc.

The bottom electrode is the iron plate with its carbon covering, and is connected with the current by conductors of sufficient area; the top electrode

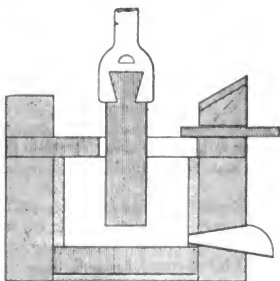


FIG 194
THE RATHENAU ELECTRIC FURNACE.

is in nearly every case a long carbon rod or block capable of regulation as to distance from the nether pole. It is held in a special carbon holder, and projects into the furnace for nearly its full length.

The current employed at these furnaces is very large, and the conductors must be ample, and this remark also applies to the sectional area of the upper pole. In one furnace, some details of which were given the author, the current employed was 2,500 ampères at 60 volts, and the yield of carbide was 5·5 kilos. per kilowatt day.

It may now be seen that the dimensions of the top carbon will influence the voltage of the current requisite for efficient working. In the Willson furnace used at Merrittton, in the United States, the 150 *kw.* machines run at 60 volts, and the current is fed through a carbon block 18 inches long, 6 inches thick, and 12 inches broad. This upper electrode is held in position by an electrically regulated chain hoist. In the Meran carbide furnaces the upper electrodes are built up of four carbons, each 50 inches long by 8 inches square. These are placed in a special mould and a mixture of anthracite and tar rammed tightly around them. They are then baked at a high temperature yielding a solid electrode about 2 feet square, which passes an alternating current of 7,000 ampères at 33 volts. In the San Marcello furnaces the carbons are only 5 inches in diameter, and each takes a current of 1,200 ampères at 145 volts.

Other furnaces may be found in which the upper electrodes are built up in a similar manner to the Meran furnaces, of 4 ins. \times 4 ins. carbons, 3 ft. long, and these are stated to be very serviceable.

The bodies of the furnaces themselves, and the feeding and running off arrangements, may be varied almost indefinitely. Instead of being stationary as shown in Fig. 194, the body may take the form of a huge crucible of 60 or 70 cubic feet capacity, and this may either be made to tilt so as to deliver its contents, as in the Heroult furnace, or it may be placed on a trolley and made a removable part of the furnace.

The Deutsche Gold u. Silber Scheide-Anstalt. of Frankfurt, manufactures an electric furnace of this last description, an illustration of which may be seen in Fig. 195. It is a square bottomless chamber lined with magnesia bricks. The top is pierced to allow of the passage of the electrode, for feeding in the raw materials and for the escape of gas. A small trolley carrying the bed-plate and nether electrode is made to run below the furnace body, and is raised by gearing until the sloping sides fit gas-tight into the body of the furnace. One cable carrying the current is attached to the bed-plate, while the other cable is connected to the upper pole. This carbon is capable of regulation for distance by a series of pulleys and hand-wheels, and carries a current of 2,500 ampères at 60 volts. It is stated that the make of carbide is 5 kilos. per kilowatt day, and the production of one ton of calcium carbide requires 1.6 tons of coke and limestone combined in its production.

As to the cost of manufacturing products in the electric furnace, one can make a very fair estimate. It is said that calcium carbide can be made at an entire cost of £8. per ton, when water power is employed to run the dynamos. If this be so, we also know that 4,500 kilowatt hours will produce a ton of carbide, so that this affords a good basis for other electro-metallurgical processes. An installation of 4,000 *k.w.* will produce 1,000 tons of aluminium yearly, or 1,100 tons of chromium. In the manufacture of carborundum, 8.5 kilowatts are required to produce a kilo. of it. Carborundum contains 66 per cent. of silica and 33 per cent. of carbon, and is one of the finest abrasive materials known.

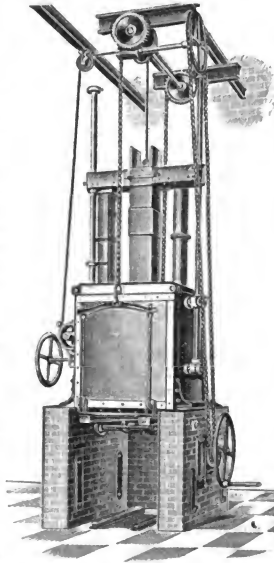
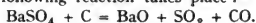


FIG. 195. ELECTRIC CARBIDE FURNACE.
(By the Deutsche Gold und Silber
Scheide-Anstalt.)

The possibilities of the electric system of producing chemical substances seem almost without limit, and the various processes now being experimented with in the Niagara area is calculated to make manufacturers by chemical methods feel somewhat uneasy. It still remains, however, to prove that many of them will be financially successful, though it should be remembered that the high temperature of the electric furnace enables cheap minerals to be employed where more expensive reagents would be needed for chemical processes. The phosphorus manufacture is a case in point. The chemical method employs a mineral phosphate, sulphuric acid and carbon, while the electrical process uses carbon and silicic acid (silica or sand). The Oldbury Chemical Company, which is virtually the American branch of Messrs. Albright and Wilson, of Oldbury, has a plant running at Niagara, making yellow phosphorus and chlorate of potash, the former product by the Readman-Parker process, in which an intimate mixture of mineral phosphate, sand and carbon is heated in the type of furnace shown at E in Fig. 193. The phosphorus distils off, while a slag of silicate of lime is tapped off at stated intervals.

The United Barium Company also has a works at Niagara, where barium sulphate or heavy spar is heated electrically in the presence of carbon, whereby the following reaction takes place:—



The present output is stated to be ten tons per day from three furnaces, each consuming 2,500 amperes at 120 volts.

In this country, the electrical furnace figures in the works of the Scottish Cyanide Company at Leven. Barium carbonate is heated by carbon electrodes in a kind of miniature blast furnace, and a current of producer gas simultaneously passed through. The barium carbonate is first intimately mixed with charcoal and briquetted, and under the influence of a large current becomes barium oxide which, at the high temperature of the furnace, absorbs the nitrogen from the current of producer gas, forming barium cyanide. This is dissolved out with water from the fused or fritted mass, and decomposed with sodium carbonate, the resulting solution being evaporated in vacuum pans and crystallised at a temperature of 4° C. It will be seen that there are many points upon which such a process as this is likely to go wrong, but the practical success may be quite possible. The problem seems to rest more upon chemical conditions than upon electrical knowledge.

Although attempts to prepare iron and steel in the electric furnace have been made for the last thirty years, they were not very successful until about a couple of years ago. During the year 1901, however, a number of installations were put to work, and these are now not only producing a very pure metal, but some of them are proving to be decidedly economical. A good review of some of these processes, by Albert Neuberger, may be found in the *Zeit. f. angewandte Chemie*, January 22nd and 29th, 1904, and in the *Electrochemische Zeit.* for 1903, to which originals the reader is referred.

It appears from all we know at present that the methods employed are nearly all of a very simple nature, and the reason why electrical furnaces

were until recently found to yield impure products with great loss of current was because the ore was allowed to remain too long between the electrodes. Not only was the current consumed unnecessarily high, but the iron took up large quantities of carbon and other impurities, while it was lying under electrical influence. In all the processes now in operation, both the metal and the slag are removed as rapidly as possible from the neighbourhood of the electrodes.

There are now about seven works in operation in Europe, making iron and steel electrically, and there are a number of others in America, and at least two works in Chili, a country well provided with ores of the right kind, and the necessary water power. The pioneers of the electro-metallurgy of iron and steel are E. Stassano, of Rome, and Dr. Hérault. The method known as the Stassano process is claimed to have been worked out so thoroughly that it is possible to obtain by it iron or steel of any desired composition. The ores used consist of rich Italian magnetites, pure hematites and limonites, to which limestone and pure charcoal are added. These are mixed together in such proportions as to yield a slag containing four equivalents of basic constituents to each molecule of silica. The materials are finely pulverised, the iron ore being subjected to a preliminary magnetic separation, and the mixture made into briquettes (see page 516, Vol. I.) with the addition of tar, so as to prevent the different constituents separating from one another in the shaft of the electrical furnace.

The furnace now used consists of a round chamber having a dome-shaped roof and openings in the sides for the two electrodes, and for a chute communicating with a hopper for the introduction of the briquettes. There are also holes at and near the bottom of the furnace for running off the molten metal and the slag, respectively, and at the top there is a pipe to carry away the gases produced during the operation. This construction may be seen in the following illustration (Fig. 196).

The briquettes, as they slide into the furnace, are melted, and flow rapidly between the electrodes, whereby the iron is at once reduced. In a later pattern of furnace, the whole appliance is made to rotate about an axis slightly inclined to the vertical, in order to ensure that the material is completely converted.

Stassano calculates that about 61 per cent. of the current is transformed into chemical energy, and that only 39 per cent. is lost by radiation and useless work. He puts down the cost of producing one ton of iron or steel at £3 15s., allowing eighteen shillings for the electrical power requiring 4,000 horse-power hours, without taking interest or depreciation into account. The escaping gases consist largely of carbon monoxide, and may become a source of revenue. The larger of the two furnaces that have been erected at Darfo requires 500 horse-power, consuming an alternating current of 2,000 ampères at 170 volts. These are average figures. At the commencement of the operation, the voltage is rather lower than that mentioned, but it gradually rises, then sinks, and at the end of the process again attains a maximum. The smelting of a charge of 30 kilos. of wrought-iron occupies about two hours, and by giving the anodes an inclination down-

wards, their wastage has been reduced to 4 cm. (1·6 inches) per hour. Wrought iron, steel, and the various iron alloys, chromium, etc., can be easily made direct from the ores in this furnace with a saving of much expense.

The Société Electrometallurgique Française of La Praz in Savoy and Dr. Héroult are the holders of numerous patents for furnaces and processes for the production of iron and steel, and of alloys of the most diverse descriptions, but of all these the most successful has been an appliance that may be

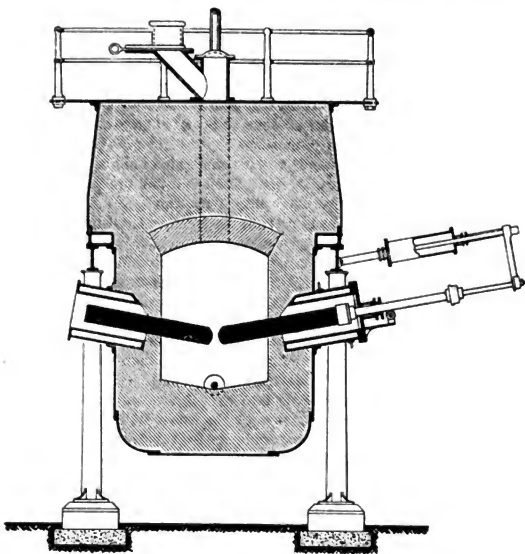


FIG. 196.—THE STASSANO ELECTRICAL FURNACE.

described as an electrical Bessemer converter, in which the electrodes are kept from actual contact with the molten metal by a device introduced by de Laval. The works at La Praz produce six tons of tool steel daily, and during the wet season the surplus current is utilised for the production of a high grade of pig-iron.

Another installation of the Héroult furnace is being made at Granbergssdal, in Sweden, where the highest grade of steel is to be turned out, the consumption of power expected being about 150 kilowatts per ton of steel.

The illustration (Fig. 197) shows the Héroult furnace worked under the system Laval. It consists of maintaining over the surface of the molten metal a layer of liquid slag, which manifests a higher resistance to the passage of the current than the metal underneath it. The two electrodes are suspended from above, with their lower ends dipping into this slag, and, owing to the comparatively high resistance, the greater portion of the current passes down through it, and through the molten metal below, which is thus kept at a high temperature without the electrodes being brought into actual contact with it. The converter is mounted in such a way that it can be tilted to empty the charge, and the rear wall is provided with holes, through which air may be blown in.

At first sight, it would appear that this furnace was only suitable for converting pig-iron into steel, but it is also possible to reduce ores, for which

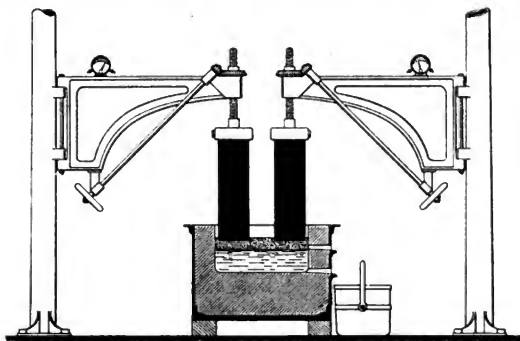


FIG. 197.—HEROULT ELECTRICAL FURNACE.
(System Laval.)

operation it is only necessary to cease blowing in the air. It is claimed that this electrical furnace possesses advantages over the ordinary Bessemer converter in that the heat is easily under control, and that it is not necessary to add ferro-silicon to raise the temperature. Three tons of steel can be manufactured in each charge in one of these furnaces, requiring the consumption of 4,000 ampères at 120 volts. Several charges can be worked off in one day, and the steel may be made free from carbon, or with any desired percentage.

In the Harmet process, as carried out by the "Fonderies, Forges et Acières, St. Etienne," the reduction is not made in one electrical furnace, but in three, which feed, the one into the other, in series. In the first of these furnaces, as shown in the illustration, the ore is fused by means of the heat of the gases escaping from the second furnace, assisted, if necessary, by

an electric current. In the second furnace, the material is made to pass through a layer of incandescent coke, the necessary air being blown in through the tuyeres, the coke being fed in through the vertical shaft. The molten material then flows into the third electrical furnace, which is merely a box furnished with a heat resisting lining. Here the reduction process is completed with the aid of an electric current introduced by means of electrodes, which dip into the supernatant slag. The purified metal and the slag are tapped off from time to time. According to the inventor, 3,600 horse-power hours are required per ton of steel, a quantity which it is expected will be reduced in the new large plant which is being installed at Albertville, in the French Alps.

The Kjellin process which is in operation at Gysinge in Sweden differs from any of the foregoing, in that the molten metal is not put into contact

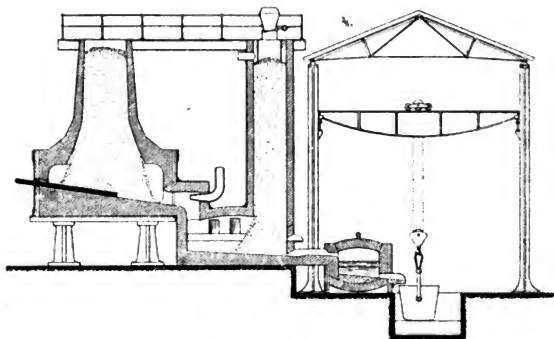


FIG. 198.—THE HARMET ELECTRICAL FURNACE.

with electrodes either directly or indirectly. The furnace is constructed on the principle of an electric transformer, the primary circuit of which consists of a coil of many turns of fine wire, through which an alternating current of high potential is sent. The secondary circuit is formed of an annular channel cut in fire resisting material, the channel being filled with the iron or steel that is undergoing the refining operation. A very large current of low potential difference is induced in this metal, and is thus raised to a red heat, causing the carbon to burn away, and other impurities to be removed. A section through this furnace is shown in Fig. 199.

In a paper read before the American Institute of Mining Engineers, by Mr. F. A. Kjellin, it is stated that the first furnace at Gysinge was put into operation in February, 1900, and with a 78 *kw.* generator 270 kilos. of steel were produced in 24 hours. The next furnace built was ready for work in November, 1900, and produced, with 58 *kw.*, from 600 kilos. to 700

kilos. of steel ingots per 24 hours. The output was not fully satisfactory, as the cooling surfaces of the walls was found to be too great, compared with the contents of the furnace, and the cost of repairs was also too high.

In August, 1901, the sulphite-pulp mill at Gysinge was completely destroyed by fire, and it was then resolved not to rebuild it, but to use for steel smelting the water power formerly absorbed by the pulp mill.

The new plant was ready to start in May, 1902, and has since that time worked satisfactorily. It consists of a furnace containing 1,800 kilos. of steel, from which from 1,000 kilos. to 1,100 kilos. are taken out by each teeming, and the rest left to keep the current passing. The furnace produces with 165 *kw.* 4,100 kilos. of steel ingots in 24 hours when charged with cold materials. The electric generator produces an alternating single-phase current of 3,000 volts, which is transformed by means of the primary coil and iron core of the furnace into a current of about 30,000 amperes in the steel forming the secondary circuit. The smelting process, as carried on at

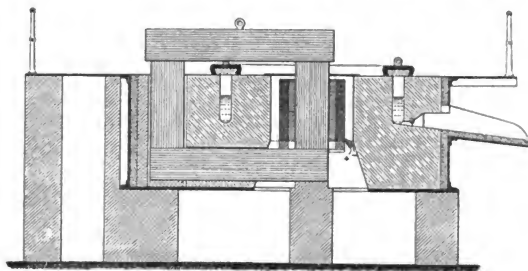


FIG. 199.—THE KJELLIN ELECTRICAL FURNACE.

Gysinge, produces only first-class steel, from the excellent Dannemora pig iron and weld iron. After teeming, about 800 kilos. of metal are left in the furnace to keep the current passing, and to this is added the proper quantities of pig iron, bar ends and steel scrap, such as experience has proved will give the percentage of carbon desired in the resultant steel. In teeming there is always less carbon in the steel than that contained in the materials charged, because the pig iron is rusty, and the steel also takes up a little silicon by reduction of the silicic acid of the lining. When the charge is molten and overheated to a suitable degree, the teeming is done in the same way as in the open-hearth furnace, by making a hole in the wall. The upper part of the furnace, as shown in the illustration, is on the same level as the working floor, and the charging is done simply by taking off the covers and putting in the materials. As the heat is produced in the steel itself, the slag is not so hot as in other steel furnaces, and consequently the workmen do not suffer much from the heat. The steel produced is, as mentioned above, of an excellent quality, unusually homogeneous, dense

and tough, easy to work cold when annealed, and less disposed to crack and warp in hardening than other kinds of steel.

To make special steels with nickel, tungsten or chromium offers no difficulties, and the alloys themselves are quite homogeneous. The cost of production depends principally on the efficiency of the furnace, and the price of the power. In the furnace now in use at Gysinge the losses have been proved experimentally to be 87.5 kw. , so that the effective power absorbed by the steel is $165 - 87.5 = 77.5 \text{ kw.}$, and, as this produces 4,100 kilos. of steel in 24 hours, one effective kilowatt produces about 53 kilos. of steel ingots in the same time. Every additional kilowatt in the furnace, when the size is not altered, increases the output by 53 kilos., and it is calculated that within a few months, when a stronger water wheel is obtainable, it will be possible to produce about 6,000 kilos. of steel ingots with 200 *kw.* As the absolute cost of labour and repair will be the same, the cost for one ton of steel ingots will be about two-thirds of the present cost, and the price of power per ton also will be sensibly diminished. At Gysinge, the cost of repair (renewing the lining of the furnace when it is worn out) was £15. From experience with this furnace it is calculated that a furnace of 736 *kw.* will produce 30,000 kilos. of steel ingots in 24 hours, when charged with cold materials. With hot materials the output is much greater. For instance, if 250 kilos. of molten pig iron are charged for each ton of steel ingots produced, the output is increased from 30,000 kilos. to 36,000 kilos. in 24 hours with 736 *kw.* Kjellin gives it as his opinion that the cost of labour and repairs for a furnace of the type shown by Fig. 109 will be less than those of an open-hearth steel furnace of similar capacity, so that where power is cheap, there is a possibility of producing steel competing with the expensive crucible steel, at a smelting cost not exceeding that of the open-hearth furnace.

There are several other furnaces mentioned in the memoir alluded to on page 406, but enough has already been said to explain the principle upon which electrical furnaces are constructed, and the practice in operating them, and as the subject must still be regarded as being in its infancy, considerable development and extension may be expected during the next few years.

Electro-Magnetic Separation — It has been customary for many years to employ machines for separating adventitious particles of iron from the raw materials used in many trades, where the presence of iron would be injurious. The miller, for instance, often uses a magnetic separator for holding back the nails and other ferric particles occurring in the grain passing into the mill; the glass-maker submits the charcoal he employs to the same process, while the machinist uses a similar appliance for separating iron-turnings from brass-turnings. All the earlier machines were constructed with permanent steel magnets, generally of horse-shoe shape, and many of them are so constructed now, though the electro-magnet is fast civilising them out of existence. It is not, however, to such appliances as the foregoing that the reader's attention will now be directed.

In describing the Stassano furnace, on page 407, it has been stated that the iron ore used therein underwent a preliminary magnetic separation,

and as this is an operation of comparatively recent origin, it may be as well to go carefully into the whole subject, as the author believes the process when it has become more fully developed will have an important bearing upon the preparation of many metallic salts and other preparations.

It has been already shown on page 498, of Vol. I., *et seq.*, that the wet method for the separation of minerals from each other becomes more and more difficult as their specific gravities converge, so that when the difference in density between two or more minerals is small, it is practically impossible to induce any separation even with the most improved forms of jigs, vanners or rotating tables. In practice we meet with many minerals so intermixed in mass that they are industrially of but little value, seeing that one or other of the constituents is often given away in order to realise the other. At one time, zinc was valueless in the presence of copper, and not only so, but nuisable, as a fine was placed upon it by the smelter. Wet methods fail to separate minerals of equal specific gravity, so that the density of chalcoppyrite being 4.2, and that of blende being 4.0, there is no possibility of inducing these minerals to separate by carrying them along in a current of water, disposed either vertically or horizontally. We may consider another case. Wolfram and cassiterite—tungstate of iron and stannic oxide—both occur together in many deposits, but water will not separate them in the usual way of vanning, as though wolfram has the high specific gravity of 7.5, cassiterite possesses the correspondingly high figure of 7.0. It would be easy to separate both of these minerals from a quartz gangue by jigs or vanners, but there the operation ends. It is also thus with copper pyrites and zinc blende, but owing to the nearer approximation of quartz to blende—2.6 to 4.0—the separation is not so easily effected as in the case of wolfram and cassiterite.

The antiquated permanent-magnet machine already mentioned was known to be capable of separating some minerals from others, but it was never considered possible to use it as an industrial appliance, capable of dealing with large bulks of mineral. In 1896, Wetherill, of Bethlehem, Penn., U.S.A., demonstrated by practical trials that on employing a field saturated with magnetic flux of a density never before applied to such purposes it was possible to separate a great number of minerals that were formerly considered to be non-magnetic. For his method, as well as for the appliances constructed for the purpose, Wetherill obtained patents in all civilised countries. His machines were improved by the present holders of the Letters Patent, the Metallurgische Gesellschaft, Act. Ges. Frankfurt-on-Main, and have again been improved and re-designed by the Humboldt Engineering Works of Kalk, near Cologne, who have many of their machines at work in all parts of the world. The separation by magnetic flux of high density is now possible in very many instances, and the graduation of that density forms an all-important point in the operation. At the Clitter's United Mines, at Gunnislake, near Tavistock, in Cornwall, a wolfram-tin ore is so successfully treated that the two products are made saleable, while at the tin mines at Carril, in Spain, the Rowan separator produces two products, the one containing 70 per cent. of wolfram associated with less than one per

cent. of tin, while the tin product contains over 70 per cent. of tin with less than one per cent. of wolfram.

Allusion has already been made to the impossibility of separating chalcopyrite from zinc blende by the ordinary wet methods, but the electro-magnetic method will easily separate Franklinite of sp. gr. 5.07 from Willemite of sp. gr. 4.18, which is done on a very extensive scale by the New Jersey Zinc Co., U.S.A. Willemite is a basic zinc silicate, while Franklinite is chiefly composed of Fe_3O_4 . A magnetic separator is also working at the De Beers Consolidated Mines, at Kimberley, operating on the diamond washings. In this case, a concentrate is produced, which in addition to diamonds, contains such ferruginous minerals as magnetite and titanite iron; these are extracted in the machine, leaving the diamonds behind.

The foregoing notes will show that the operation of the magnetic separation of minerals is an accomplished industrial process, and that it promises still more in the near future. It has already been mentioned that Wetherill rediscovered what others had noticed before him, that many minerals considered to be non-magnetic were in reality feebly magnetic, and that when placed in a current of magnetic flux of high density they were readily attracted by the magnet. For technical purposes, therefore, it will be convenient to classify all minerals as:—

- (1) Magnetic,
- (2) Feebly magnetic, and
- (3) Non-magnetic.

In the first class, we may place the iron group at the head of the list, most iron minerals being more or less magnetic, though there are some notable exceptions, of which ordinary iron pyrites is a good illustration. Nickel, cobalt and manganese follow iron in this list, but the behaviour of the mineral compounds of these metals is extremely erratic. Amongst the iron group, the oxides and sulphides of iron deserve careful study, and the same may be said of the titanate and tungstate. Iron oxides or iron sulphides may be so feebly magnetic as to resist all attempts to attract them by means of the magnet, but, as we shall see presently, they may be artificially brought within the magnetic class.

Amongst the feebly magnetic minerals, we have a good illustration in the well-known zinc blende. A pure blende, that is to say, one containing but traces of pyrites, is not attracted by currents of fairly high density. It is true that a roasted blende will often yield a small percentage to magnetic treatment, but the portion so withdrawn will be found due in most cases to the pyritic contents. In one experiment made by the author upon a blende containing 60 per cent. of ZnS , and 35 per cent. of silica, a high density of magnetic flux separated absolutely nothing, while, after heating to 600°C . in a closed scorifier, about one per cent. of magnetic pyrites was drawn out. Feebly magnetic minerals, such as blende, vary in the extent of their magnetic permeability, so that some of the particles from the same lump of ore will be attracted to the magnet, while others will be uninfluenced. Schnelle, in the discussion following a paper read by him before the Verein zur Beförderung des Gewerbflusses, in 1902, is reported to have

said "pyritic blende can be treated direct when the blende possesses sufficient permeability to enable its separation from the almost non-magnetic pyrites." From this it would seem that the zinc blende contemplated by Schnelle was feebly magnetic *per se*, but in those samples examined by the author, the feeble magnetism of some of the particles appeared to be due to the presence of a small quantity of ferrous substance distributed about the mass. In fact, the particles of pure blende when heated to 600° C. in a closed scorifier were yellowish brown and nearly transparent, in slices of one-sixtieth of an inch in thickness, while blende that proved to be feebly magnetic, on being subjected to similar treatment, became black and opaque. The author does not wish, however, to cast any doubt upon the statement that some varieties of blende in the pure and unroasted state may be feebly magnetic.

But there are mineral particles that refuse to be coerced, no matter what amount of magnetic influence is brought to bear upon them. These minerals are quartz, non-ferrous gangues of nearly every description, heavy spar, etc. These minerals help to form Class 3 of our list—non-magnetic.

Magnetic ore-dressing or concentrating must be carried out upon a well-dried product, and, moreover, the mineral must be efficiently crushed or pulverised, and evenly sized, in order that the process may be carried on successfully. The necessity for fine crushing or otherwise must of course depend upon the nature of the mineral, as it will be readily understood that the process of disintegration need not be carried further than is necessary to break up the mass into its constituent minerals. If this is effected upon particles just passing a 30-mesh screen, it is a waste of time and energy to reduce the mineral so that it will go through a 60 or a 90 mesh screen, and when it is considered that most fine ore requires briquetting before it can be smelted industrially, the evils of too fine a disintegration will be apparent. It is necessary, however, to arrive at such a degree of comminution that each particle is homogeneous. In separating an iron ore from its accompanying quartz gangue, a particle consisting of equal volumes of iron ore and quartz would be drawn to the magnet, and the quartz would dilute the value of the product—in other words, the separation would be imperfect, but the magnet has nevertheless done all that it should be called on to do.

It has already been mentioned that some minerals, as iron pyrites, or copper pyrites, are generally absolutely non-magnetic in the natural state. It has been found that if such minerals be subjected to heat, or to heat and air, they may be rendered magnetic, so that if a pyritic blende in which the magnetic permeability of both minerals is about equal, and, therefore, not suitable for magnetic separation in the natural state, be subjected to heat, either in close or open vessels, an easy separation may be made. The result of the subjection of such minerals to the action of heat in closed vessels is the expulsion of some of the sulphur from the pyrites, the bisulphide (FeS_2) becoming magnetic pyrites (Fe_7S_8), seven molecules of the bisulphide losing six atoms of sulphur in the operation. When a pyrites is carefully calcined in air, a strongly magnetic oxide of iron is formed. It is quite possible that the reason for this may be the simultaneous formation of the two higher

oxides of iron, the peroxide (Fe_2O_3) and the ferroso-ferric oxide (Fe_3O_4), commonly called the magnetic oxide.

A sample of Pilley's island pyrites examined by the author, and found to contain 52 per cent. of sulphur, after calcination in air, yielded a residue weighing 66.6 per cent. of the original ore, which proved to be strongly magnetic. The burned cinders from ordinary pyrites kilns are nearly always found to be strongly magnetic.

The foregoing alterations in the magnetic permeability of minerals by the action of heat, together with the varying degrees of natural permeability, renders it possible to perform many separations by means of properly constructed electro-magnetic machines, of which we may now examine the construction.

There are several systems upon which electro-magnetic separators are constructed, and these may be arranged in four classes, as follows :—

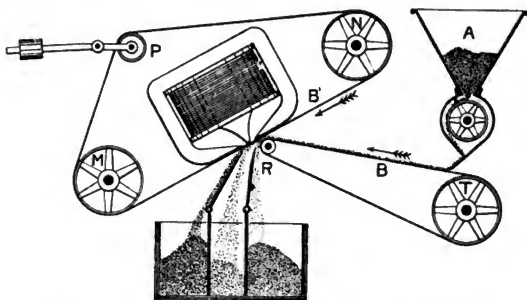


FIG. 200.—ELECTRO-MAGNETIC SEPARATOR, "FALLING IN AIR" TYPE.

- (1) Separation of the particles while falling in air.
- (2) Separation while travelling upon belts.
- (3) Separation by adhesion to magnets.
- (4) Separation in presence of water.

The difference between the first and second classes will not be apparent to the beginner without some further explanation. Both of these systems involve the use of belts for carrying the minerals into the magnetic field, but at this point the similarity ceases, and there is no difficulty in detecting the difference of type. In the first system, the separation does not take place upon the belt, which simply acts as a conveyor, and from which the disintegrated mineral falls towards the receptacles placed to receive it. The powerful magnetic flux passing through the air space between the poles of the magnets acts upon the falling magnetic particles, deflecting them from their normal direction, so that they fall, not as they leave the conveying belt influenced alone by gravity, but as directed by the situation and in-

tensity of the magnetic field. The illustration (Fig. 200) shows the chief characteristics of this system.

The second system, known also as the cross-belt type, is constructed in such a manner that, while the belt running between the two poles of an electro-magnet acts as a carrier for the mineral, another belt, or series of belts, running at an angle to the main carrying belt, is employed to remove the magnetic material, and to give it a motion that deposits it in a receptacle or series of receptacles placed at the side of the main belt, the waste or gangue, being unattracted, passing away in another direction. This system has many advantages which will be explained later on, but in order to familiarise the reader with the action of this system, the following diagram has been prepared :—

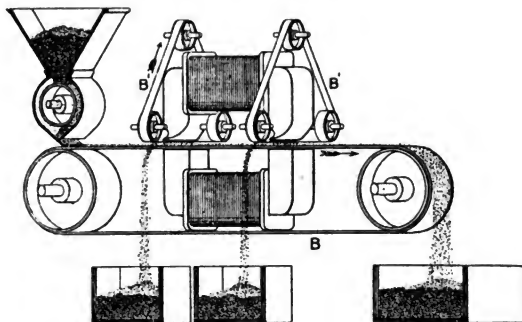


FIG. 201.—ELECTRO-MAGNETIC SEPARATOR, "CROSS-BELT" TYPE.

The third system mentioned in the classification has been called the roller type, and has been modified in construction by several engineers. In this system, a magnetised iron roller or cylinder is employed, to which the magnetic particles adhere, leaving the non-magnetic particles to fall away. The magnetic particles have, of course, to be detached from the roller or cylinder, and this is effected in various ways, according to the construction of the machine. In some of them, a wire brush, or a brush composed of stiff bristles, sweeps off the magnetic particles from the roller, or a scraper cleans them off, while in another pattern the current of magnetic flux is interrupted at intervals, at which points the particles cease to adhere and fall into a receptacle placed to receive them. In yet another pattern, the roller placed between the poles of a powerful magnet becomes charged with induced magnetism, which, in rotating, liberates the adhering magnetic particles each time the neutral point of the roller is reached, in its rotation in the magnetic field. In another form known to the author, the roller is

fitted with a large number of small electro-magnets, upon which the particles are dusted from the feed hopper; the magnetic particles adhere to the pole-pieces of the magnets fixed on the periphery of the roller, which at each half revolution of the roller are demagnetised by cutting off the electric current, again becoming magnetised at the commencement of the second half of the revolution by a contact which switches on the current again. The roller type of machine may be better understood by reference to Fig. 202.

Knowles' "New Century" Magnetic Separator, made by the American Concentrator Company at Joplin, Mo., U.S.A., comes strictly under our third class, but though the roller of the typical machine is expanded into a belt, the belt itself is studded with soft steel rivets to which the magnetic particles adhere during their passage through the machine. In this separator the soft steel rivets become magnetised by induction in passing through the magnetic field, quickly losing nearly the whole of their magnetism as they recede, and so dropping the particles that have adhered to them.

The fourth system of our classification comprises the wet magnetic separators, which have but only recently been brought to a satisfactory state of perfection. It is true that several are at the present time in use industrially, but so little is known of their performance that any comparison



FIG 202.—ELECTRO-MAGNETIC SEPARATOR,
"ROLLER" TYPE

with machines of the first three systems is out of the question. The wet magnetic preparation of strongly magnetic iron ores has been carried out on the manufacturing scale for some years at Pitkäranta, in Finland, and presents no great difficulty, though the water intervening between

the individual particles apparently hinders the action of magnetism, with the result that this method of separation requires a comparatively strong magnetic flux, and a correspondingly large electric current. The wet method has been tried for the purpose of separating zinc-blende from sulphide slimes, such as those coming from the Broken Hill mines, but so far without success. A separator of the roller type (Fig. 207) was shown in action as a wet magnetic separator at the Dusseldorf Exhibition of 1902, separating spathic iron ore from zinc blende, but the comparative difficulty of separating feebly magnetic material by such machines, together with the small yield from such separators, and the necessity for briquetting afterwards, have not given the experimenters much encouragement.

The construction of machines under the various systems demands some attention to at least three distinct points, the mechanical details, the magnets, and the magnetic flux required. As to the first point, there may be very many ways of carrying out the mechanical details, both of bringing the pulverised particles into the magnetic field and of delivering them outside the influence of the machine. The power necessary for these objects should, of course, be reduced to a minimum.

The magnets being the principal parts of the machine require much study, as to their dimensions, arrangement and form, and it is well to remark

here that the elements of magnetism and electricity must be thoroughly understood by the reader, as otherwise he will be unable to follow the subject as it is necessary to describe it. Intimately connected with the question of the magnets is that of current and the density of the magnetic flux. The current required for a good pattern of electro-magnetic separator is but small, but the way in which the magnets are constructed and wound determines whether they will do their work satisfactorily or not. The actual current required for the magnetic portion of a good machine is considerably less than one Board of Trade unit, it being possible to separate four tons of roasted pyritic blende per hour with a current of 500 watts.

In Schnelle's paper already alluded to, stress is laid upon the novel system of magnets employed in a machine used with great success in Germany for the separation of spathic iron ore from zinc blende. This system is shown in the diagram (Fig. 200), the novel arrangement of the poles being more clearly seen in Fig. 203 A. The principal pole N lies in the centre, with the S S poles on either side, an arrangement which Schnelle states produces underneath them a "projecting" magnetic field with a high density of flux, and by the juxtaposition of two fields in this manner the magnetic zone is at the same time extended considerably in the direction of the lines of force, which is of great advantage in the separation of minerals.

The system of magnets in Fig. 201 will be seen to differ from that just described. Instead of two sharpened or wedge-shaped poles opposed to each other, the lower magnet is flattened, whereas the pole of the upper magnet is cut away in the form of a wedge, as further shown in Fig. 203 B, so that when magnetic particles are brought into the field they will be attracted upwards towards the wedge-shaped pole, although the distance from the lower pole be comparatively small.

In the third or roller type of machine, the roller becomes magnetised, either by induction or otherwise, the magnetic particles adhering to it, so that this class of machine will do its work efficiently with a small current. This brings us naturally to the difference between one form of magnet and another, as, according to the purpose for which it is intended, so must the magnet be constructed and mounted. Broadly, magnets may be of two kinds :—

- (1) Those required to sustain heavy weights through the medium of an armature.
- (2) Those required to exert an attractive force at a distance, *i.e.*, through an air circuit generally.

Those in the first class are called portative magnets, and the amount of force possessed by them depends on the area of the polar surfaces and the intensity of the magnetic flux passing through them. When soft iron is

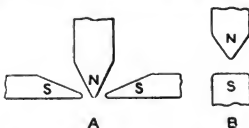


FIG. 203.—NOVEL ARRANGEMENT OF POLES.
(The Humboldt Engineering Co., Kalk.)

magnetised to saturation, each square inch will support a load of 200 lbs., but if the polar surfaces are merely increased without due regard to increase in the magnetic flux, the flux density may be reduced and the portative effect become less than before. It has been found by experiment that the attractive force upon a soft iron armature held by two polar surfaces increases directly with the surfaces involved, when the density of the flux remains constant; but by doubling the magnetic flux, all other things being equal, we quadruple the portative effect until saturation is reached, so that the attractive force increases as the square of the magnetic intensity through the polar surfaces. The particles of mineral prepared for electro-magnetic separation will probably vary from the one-sixth of an inch in diameter, to the one-hundredth part of an inch, or even less, so that a little consideration will show us that the rules and conditions appertaining to the construction of portative magnets will not interest us much in this connection.

In order to obtain a powerful electro-magnet of the second class, for attraction at a distance, without the intervention of an armature, we must have a core area suitable for the work to be performed. This must be magnetised to saturation, that is to say, the greatest possible current of magnetic flux must pass between the pole areas, with a high degree of intensity. As in the case of portative magnets, the attractive force increases directly with the surfaces involved, and as the square of the magnetic intensity, so that when it is desired to increase the attractive force an increase in the density of the magnetic flux is the most important consideration. The principles of construction, together with a fair knowledge of the theory of the subject, should be mastered before any attempt be made to build an electro-magnet for any definite purpose, and the author desires to call the reader's attention to Sprague's "*Electricity: Its Theory, Sources and Applications*"* as a work which will be found as practical as it is interesting; pages 81-100, 298-340 and 454-534 will be found specially useful to the student of electro-magnetic separation.

The amount of magnetic flux in any non-ferric circuit, such as that of an active coil of wire, without an iron core, increases with the magnetising current. When a current, say, of three ampères is passed through a coil consisting of a given number of turns of wire, the amount of flux would be doubled by sending a current through of six ampères. Further, if the number of turns in a coil be increased, we also increase the magnetic flux, so that a current of three ampères flowing through a coil of 200 turns of wire will yield double the flux that a coil of 100 turns would. A single magnetising turn of wire on the core bobbin, traversed by a current of one ampère, is known as one "ampère turn," and the magneto-motive force (MMF) varies directly as the number of ampère turns. A coil with 100 turns of wire, carrying a current of one ampère, would be said to possess "100 ampère turns," but if the coil conveyed a current of six ampères, it would be called 600 ampère turns. It will thus be seen that there may be several means of arriving at the same end—all other things being equal, we may have the

* London: E. & F. N. Spon, Third Edition, 1892.

same magnetising effect by applying a current of three ampères with 200 turns of wire, one ampère with 600 turns or six ampères with 100 turns of wire. In practice, however, these three methods would not be quite identical, owing to the increased resistance of the longer wires, and the tendency to heat in those of smaller cross-section.

We have already seen on page 370 that the electrical current (C) in ampères may readily be calculated on knowing the electro-motive force (E) in volts, and the resistance (R) in ohms, so that we have means at our command for ascertaining the current necessary for all magnetic purposes, when the required magneto-motive force is known. The unit of magnetic intensity, or, as it is sometimes called, the density of the magnetic flux, is the "gauss," which is the number of "webers" passing through an area of one square centimetre. The intensity practically necessary to saturate very soft iron, such as is ordinarily employed in the construction of the best electro-magnets, is 20,000 gaussses, or in other words, 20,000 webers per square centimetre. Cast-iron is usually saturated at 10,000 gaussses, while half of this density, or 5,000 gaussses, will saturate hard steel. For all practical purposes the weber is calculated from the ampère turns and *vice versa* on knowing the resistance, or reluctance as it is called, to the passage of the magnetic flux. The unit of resistance, or reluctance to the passage of the flux, is called the "øersted," which is equal to the resistance of a layer of air, one centimetre in thickness, measured between parallel faces, so that by knowing this it is easy to ascertain the number of ampère turns required for any given density of magnetic flux. The gaussses multiplied by the polar area, measured in square centimetres, will give the webers of magnetic flux, and the webers multiplied by the øersteds and divided by 1.25 will give the number of ampère turns required. The diameter and length of wire is regulated by the ampères of current required and the E.M.F. at command, the resistance in ohms being a factor in the equation. For further information respecting the characteristics of the magnetic flux the reader is again referred to Sprague's work, already mentioned.

We may now profitably turn to some electro-magnetic separators in actual industrial use, describing them in the order of the classification on page 416. The first system was described on that page as the "falling in air" type, by which it is to be understood that a thin stream of magnetic particles mixed with non-magnetic particles is caused to flow from a receptacle or hopper, so placed as to allow the stream to fall in close proximity to an electro-magnet, the attraction of which causes the magnetic particles to leave their normal path, becoming deflected towards the magnet. This action of the magnet upon falling magnetic particles is clearly seen in diagram (Fig. 200), but a better illustration of such action is shown by Fig. 204, which illustrates the "ring" type of machine made by the Humboldt Engineering Works, at Kalk, near Cologne. The machine is an admirable example of the value of magnetic deflection. The machine itself is absolutely motionless. The powdered ore (in this case a roasted pyritic blende) is fed from the circular hopper placed over the magnet, which is of Romers-

hausen's ball type, consisting of a hollow cylinder closed at one end, into which fits an iron core with a magnetising coil round it. The ore having reached the lower end of this cylinder falls around its periphery, and thus comes under the influence of the magnetic flux which attracts the magnetic particles towards the central core, while the non-magnetic particles fall in a straight line under the influence of gravity alone. The result is seen in the illustration (Fig. 204), taken from the photograph of a machine at work; the non-magnetic particles are seen falling as a thin sheet all round the periphery, which, when they reach the floor, pile up as an annular ring, while the magnetic particles being all deflected to the centre pile up as a circular



FIG. 204.—ELECTRO-MAGNETIC SEPARATOR.
(The Ring Type of Machine.)

heap. In the actual construction of the machine a double casing is placed under the magnet, which carries the magnetic particles into one receptacle and the non-magnetic particles into another.

Another type of machine on the first system is shown by Fig. 205, which is styled by the Humboldt Company as the Vb3 machine, and specially adapted for the separation of cupreous pyrites from zinc blende. As may be seen from the illustration, the poles of the magnets are disposed and shaped as already shown in Figs. 200 and 203, the broad belt running between the poles simply carrying the pulverised ore into the magnetic field. The separation takes place at the moment when the particles are falling freely in air, the magnetic particles being drawn out of their normal path

as already explained, while the non-magnetic portion falls close to the pulley. Particles that are not homogeneous, *i.e.*, composed of both magnetic and non-magnetic substance, form an intermediate product, and this can be separated for further treatment by carefully adjusting the separating partitions between the various receptacles. Further on, this middle product will be alluded to again.

The capacity of the machine naturally depends upon the permeability of the material and the size of the particles, but when working on pyritic blende Schnelle states that 30 kilos. per hour (66 lbs.) may be reckoned on, per centimetre width of belt, so that a belt serving a pole half a metre wide would treat 1,500 kilos., or nearly a ton and a half per hour. Schnelle also states that the power consumed in driving the feeding worm and the belt pulleys does not exceed one-tenth of a horse-power per ton, while the consumption of current for the electro-magnets, when separating spathic iron ore and blende, is about 100 watts per ton, or less than one-seventh of an electrical horse-power. At first sight, the wear and tear of the belts would appear to be an important item, but in practice this has not been found so, as they will last 30 days of 20 working hours each, the expenditure under this item reckoning out to about half a farthing per ton.

We now arrive at the second system of electro-magnetic separation, in which the belts are not merely employed for conveying purposes, but form a bed from which the magnetic particles are picked out, by magnets working over it, these being protected and aided by other belts running at an angle to the main belt. A diagram showing the principle upon which this type of machine is constructed has been given in Fig. 201; it remains now only to illustrate a practical working machine, which appears as Fig. 206. The illustration shows a Rowan separator, erected by the Humboldt Engineering Works at the tin mines at Carril, in Spain, where it has already been mentioned a separation of the two minerals, wolfram and cassiterite, is being worked so well. It will be seen that the machine is furnished with four cross-belts, each of which takes off from the main belt a product determined by the density of the magnetic flux in the electro-magnets, between the poles of which each cross-belt works. The feed is evenly distributed over the full width of the transport belt running between the poles of the electro-magnets, the construction of which has already been shown in Fig. 201. The cross-belts also run between the poles, and touch the upper wedge-shaped pole, and when the machine is working the magnetic particles are lifted out of their place upon the transport belt, and become adherent to the under side of the cross-belt, so long as it is under the influence of the magnetic zone. The cross-belt in travelling at right angles to the main belt thus picks up and carries the magnetic particles beyond the edge of the main belt, where, free from the magnetic influence, the particles fall into a chute placed to receive them, as shown in the illustration.

The capacity of a machine of this type depends in a great measure upon the thickness of the layer of material conveyed by the main belt, and also upon the speed of all the belts, and it will also be seen that the capacity may be increased by multiplying the systems of magnets so as to have

four or six in simultaneous operation. A machine of this kind with six cross-belts, and the magnets with poles 45 centimetres wide, should be able to treat four tons of pyrites blende per hour, or, roughly, 4 cwts. per inch per hour. The cross-belt machine also enables us to separate several minerals of different degrees of magnetic permeability. Monazite sand is a good instance of this kind of separation; in the machine illustrated by Fig. 206 the cross-belts at the four poles will withdraw, one after the other, first, titanite iron; second, rutile; third, monazite, while the quartz runs off the main belt as the non-magnetic product. In summing up the merits of

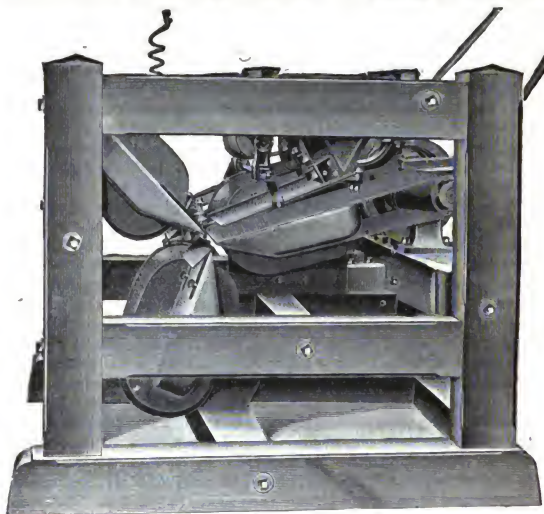


FIG. 205.—HUMBOLDT'S MAGNETIC SEPARATOR.
(Type Vb3.)

the cross-belt type with the first system here described, Schnelle states that the former possesses many advantages, seeing that the lifting of the magnetic particles from their bed requires comparatively strong magnets, and consequently the consumption of electric current is higher. This factor, he says, is but of small moment in the case of strongly magnetic minerals, but with those that are only feebly magnetic it is preferable to employ the first system, or divergence from the line of fall in air.

The third system of magnetic separation is that in which a simple or compound roller is put into the magnetic condition, and the prepared

mineral dusted lightly over it ; the magnetic portion adheres to the cylinder and is detached at stated intervals or continuously with scrapers, brushes, or some other mechanical appliance, while the non-magnetic particles fall from the roller during its revolution, under the influence of gravity. In other machines of the roller type, the roller is made to revolve between the poles of a powerful electro-magnet, so that it becomes magnetised by induction, and the magnetic particles adhere thereto, whilst the non-magnetic particles are thrown off from the roller in a curved path. The particles adhering to the roller are carried round upon it, and, according to their magnetic permeability, leave it sooner or later, as, between the poles there is, in the

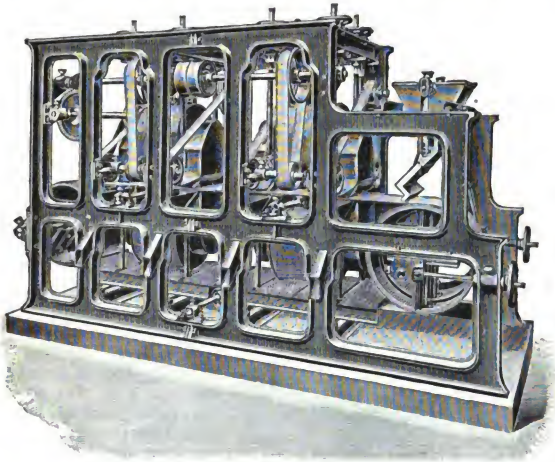


FIG. 206.—THE ROWAN ELECTRO-MAGNETIC SEPARATOR.
(Cross-belt Type, Ic4.)

field in which the roller revolves, and consequently in the roller itself, a neutral zone, where the change of polarity takes place, so that by placing partitions in suitable positions it is possible to collect several different products. This type of machine has been found suitable for very feebly magnetic minerals.

In yet another type of machine, the roller periphery is studded with plates or discs forming pole pieces to a number of electro-magnets in which the magnetising current is interrupted once in each revolution. The pulverised mineral is fed upon the upper portion of the roller, and the plates or discs being then magnetised, the magnetic particles adhere and are carried

round by the roller to a point at which the current is cut off, and the discs become demagnetised. The magnetic particles then fall from the surface of the roller, and are guided by a suitable partition into a receptacle upon one side of the roller, while a similar vessel upon the other side catches the falling particles of non-magnetic material together with such particles of magnetic material as may have escaped the action of the magnets. One thing to avoid in all roller machines is the complication and multiplication of detail. In a continuous running machine, working perhaps for twenty hours out of the twenty-four, the simpler the construction the better, and the author is unable to see how it is possible to construct a more simple

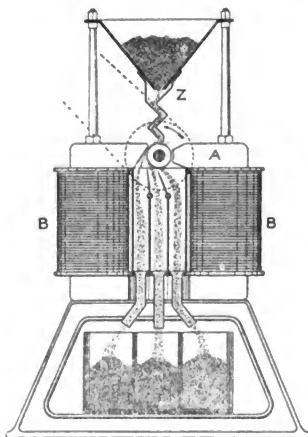


FIG 207.—
ELECTRO-MAGNETIC SEPARATOR ROLLER TYPE.
(The Humboldt Engineering Works, Kalk.)

machine on the roller type than is described and illustrated by Schnelle in his paper already alluded to. It is true that the roller is now built up of alternate magnetic and non-magnetic discs instead of the plain roller at first employed, but this is simply to give the necessary local concentration to the emerging lines of force, and does not add to the complication of the apparatus.

The illustration (Fig. 207) shows the simplicity of this form of machine, which is described by Schnelle in the following words :—The magnetic force is excited in the stationary magnetic system by the coils B B. The lines of force passing from pole to pole strike right through the roller, and form on it induced poles similar to the so-called armature poles of a dynamo, but with this difference, that in

this case the induced roller poles show a concentration of the lines of force at the point of least distance from the stationary magnetic poles. Besides this concentration of the entire field, local concentrations of the lines of force are produced on the surface of the roller. In consequence of the Foucault currents produced by the constant changes of polarity, it has been found advantageous to build up the roller by placing next to one another rings or discs of magnetic and non-magnetic material, forming in this way a cylindrical roller, in which the wearing away of the discs is little to be feared, as the material simply flows over the surface. The material is brought on to the surface of the roller, and is attracted by the induced

poles, clinging to it, and being carried with it in its rotary motion is finally thrown off in the neighbourhood of the neutral zone. By the divergence of the streams of material, non-magnetic on the one hand and magnetic on the other, quite a distinct angle of separation is caused, which may be observed even at a distance, and is but little influenced by variations in the speed of rotation. This forms the criterion of a clean separation.

The fact that this action goes on at the surface of the roller, without being interfered with by the attraction of the stationary magnetic pole, is due to the higher local concentration of the lines of force on the surface of the roller. The disturbing influence of the stationary pole may naturally be most easily overcome by delivering the material directly on to the roller, the attraction of which then greatly preponderates over that of the comparatively distant stationary pole.

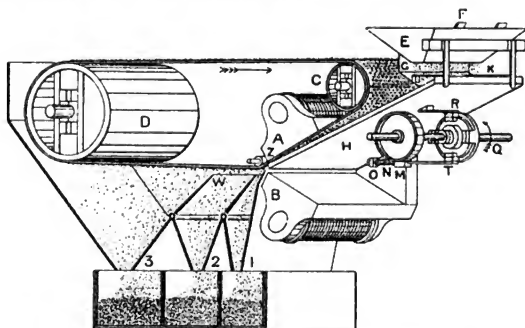


FIG. 208 --KNOWLES' NEW CENTURY MAGNETIC SEPARATOR.
(American Concentrator Co., Joplin, Mo.)

The "Knowles" concentrator has already been mentioned on page 418 as belonging to the roller type. A projection of the details of this machine may be seen in Fig. 208, which will enable the reader to follow the methods of construction and operation.

Referring to the diagram, A and B are cast steel pole pieces having plain under surfaces inclined toward each other and of opposite polarity. C and D are wood pulleys around which moves a special rubber belt in the direction of the arrow. Through this belt from the inside surface, which comes in contact with the pulleys, are driven soft steel rivets. A burr with turned up serrated edges is placed over the end of the rivets protruding through the belt on the outside and riveted down. There are about 300 of these rivets placed in every square foot of the belt. E is a feed hopper automatically supplied from the storage bin situated above the machine. G is a shaking pan underneath the opening in the bottom of the hopper.

controlled by the gate F. The function of the pan is to give a uniform distribution of the feed over the bottom of the shaking trough H.

This shaking trough, which is suspended by hickory spring suspension rods, extends entirely under the plain surface of the upper magnet A, and terminates at the point Z, where the two pole pieces nearest approach each other, being at all points above the neutral line. Q is a horizontal shaft to which is keyed a disc with four pole pieces inside of which and rotating with the shaft is a coil of copper wire. Centred on the same shaft, but not keyed thereto, is another disc with four pole pieces R, being the outside poles. The shaft is made to rotate in the direction indicated by the arrow, and the electric current is introduced to the coil through slip rings on the shaft.

It will be noted that the tendency will be for the outside pole pieces to rotate with the inside pole pieces in the direction of the arrow, for the reason that the apparatus becomes a rotating magnet when electrically charged, and the pole pieces would, of course, follow each other, and would do so indefinitely were it not for the resistance offered; this resistance is utilised in shaking the feed trough H, the upper pole pieces R being connected by a piece of thin hickory, and attached to the under side of the shaking trough H at L. The lower pole piece opposite R at T has a rod attached to it extending through a fixed beam M, and a coil spring N, with a nut O, giving this spring any desired tension.

When the shaft Q with the four inner pole pieces revolve in the direction of the arrow, the outside pole pieces will follow in the same direction, pushing the shaking trough H towards the machine until the compression of the spring N is greater than the force due to the attraction of the inner pole pieces for the outer pole pieces. At this instant the outside pole pieces will quickly slip backwards in the opposite direction from that shown by the arrow, until the pole pieces R meet S, when it will again be carried forward, and likewise four times during each revolution of the shaft Q. The shaking trough is given a slow motion forward and a quick motion backwards. The magnet coil in this rotating magnet is connected in series with the main magnet coil exciting the pole pieces A and B. To stop the feed it is only necessary to throw over the switch, and should anything become wrong with the dynamo or the wiring on the main magnet coils by which the pole pieces cease to be excited and perform their work of separation, the feed automatically stops at once. By the spring connection K the pan G is given the same shaking motion as the feed trough H.

When the coils of the main magnets are supplied with an electric current and the feed hopper E with the mixed ore to be separated, the lines of force between the two pole pieces will be condensed at the point Z, and their intensity will decrease in every direction from that point. In other words, as the material comes down the feed trough H it approaches through a magnetic field of gradually increasing intensity, until it reaches the point Z, where the field has reached its maximum strength. The belt carrying the soft steel rivets and moving in the direction of the arrow at a speed of about 200 feet per minute comes in contact with the under surface of the pole

piece A. A lubricated roller is placed at the point Z to prevent undue friction in making the angle to the horizontal as it proceeds to the pulley D.

As the soft steel rivets in this belt approach the pole pieces A and come under the influence of the lines of force emanating from the magnet, they become induced or secondary magnets, and the highly magnetic particles in the mixed ore coming down the shaking trough H leave the trough against gravity and attach themselves to the serrated edges of the burrs and as the magnetic material proceeds down the trough, and reaches a point where the intensity of the field is sufficient to lift it, the particles instantly attach themselves to the induced magnets, the particles of least magnetic permeability not being affected until the point Z is reached, the non-magnetic material remaining in the trough H fall off the end of this trough at Z into the first compartment and is delivered through the first opening and shute.

The middlings or particles of slightly magnetic permeability will be the first to detach themselves from the induced magnets, as they leave the point Z into a field of gradually decreasing intensity, and will fall from the induced magnets into the second compartment, before reaching W, and be delivered through the second shute. The particles of greatest magnetic permeability will continue to remain attached to the induced magnets in the belt, and will not entirely detach themselves from these magnets until they have receded from the point Z far enough to have lost their induction and become demagnetised. The space from Z to the pulley D is about 48 in., and throughout this length the magnetic material drops from the belt at every point like a shower of rain. No brush is required at the pulley D to remove any magnetic material from the belt. The point W can be changed at will, and as many or as little middlings made as is desired.

The capacity of this machine depends, of course, upon the width of the belt, and the machines are made with belts varying from 6 ins. to 36 ins. wide. A machine with a belt 6 ins. in width has a nominal capacity of 7 tons per 24 hours, and requires a current of 3 ampères at 110 volts, it occupies a floor space of 6 ft. by 3 ft., and requires about one-quarter of a horse-power to work it. The largest machine, with a 36-in. belt, will treat 46 tons of material per day of 24 hours, consuming 20 ampères of current at 110 volts and requiring $1\frac{1}{2}$ horse-power for the mechanical operations, the floor space occupied being 8 ft. square.

The fourth, or "wet" system of magnetic concentration, has been well described by Prof. H. Louis in a paper read before the Iron and Steel Institute in May, 1904. The description refers to the Karr and Glitter mines in Sweden, which produce an ore containing about 35 per cent. of metallic iron, existing nearly entirely in the form of magnetite (Fe_3O_4). The ore is first reduced in a Gates crusher (see Vol. I., p. 460), and the half-inch cubes thus produced are then reduced in wet Gröndal ball-mills. In these latter, a current of water sweeps away the comminuted particles, the fineness of which is regulated by the volume of water passing through the mill.

The pulp leaving the Gröndal mills passes into the magnetic separators, each consisting of a magnetic slime-box combined with the separator proper. The capacity of the concentrating plant is at least 200 tons per day of 24 hours,

and requires a current of 24 ampères at 120 volts, or about 4 H.P., while less than one horse-power is necessary to drive the drums. In his paper, Prof. Louis describes the concentrators and their working as follows:—The separators consist of an ordinary V box receiving a stream of clear water. Between each pair of these V boxes is a powerful horizontal electro-magnet, either pole of which terminates in a hatchet-shaped pole-piece, the edge of which nearly touches the level of the pulp in the box. The dimensions of the box and the velocities of the pulp and clear water currents are so arranged that everything except the finest slimes settles in the box and passes through a pipe to the magnetic separator, the fine slimes overflowing. Any magnetic matter contained in these slimes is arrested when it comes within the very powerful magnetic field produced by the wedge-shaped pole-piece, and accumulates at the surface of the water until it forms masses of such size as to drop down and be carried away through a pipe by the issuing stream of water. The object of this simple device is thus to get rid of the bulk of the non-magnetic slimes, whilst at the same time ensuring that none of the magnetic material shall be lost; it seems in practice as if the particles of magnetite once magnetised in this way retain some magnetic polarity and have a certain tendency to cohere, and are therefore less troublesome than ordinary slimes. The pulp freed from slimes now passes to the separators proper. A magnet with pole-pieces of the same shape as those used for the slime-boxes is surrounded by a drum composed of alternate bars of soft iron and brass. This drum rotates at 100 revolutions per minute about 1 in. above the surface of the pulp, which traverses a pyramidal box, this being divided into two compartments by a partition reaching nearly up to the top of the box. A stream of clear water entering and rising up on one side of the partition carries all the pulp well over the edge of the latter, and thus into close contact with the drum. The bars of iron composing the latter become powerful magnets so long as they are within the strong magnetic field of the pole-piece, and they therefore pick up all magnetic particles from the stream of pulp. The remainder of the pulp drops down on the other side of the partition, and is carried off by the stream of water into a launder. The pure magnetite is lifted by the drum to the very edge of the magnetic field, where it is thrown off by the speed at which the drum revolves. The middlings, consisting of particles that are in part magnetite and in part barren rock, containing about 55 per cent. of iron, 0.5 per cent. of sulphur, and 0.003 per cent. of phosphorus, are flung off before they reach so weak a part of the field; these are returned to the ball mills for re-crushing, and pass again to the separators with the ore pulp in the ordinary way.

It may be as well to state that the concentrates are briquetted and burnt in a special kiln (before being introduced into the blast-furnace) at a temperature of about 1,300° C., at which magnetite agglutinates sufficiently to form a firm and hard briquette, capable of withstanding very rough usage.

We may now turn to some practical work performed with machines constructed specially for this purpose. It has already been noted that in the wolfram-tin mines at Carril, in Spain, a separation of wolfram

from cassiterite is so completely effected that the tin product contains on an average but one per cent. of wolfram, and that the wolfram product contains but one per cent. of tin. This is an example of a good and clean separation, which is only to be gained by a careful study of the ore, to be treated, with several types of machine, and made with due regard to the nature of the mineral, its chemical composition, and the purpose for which the operation is being performed. It may be that the operation is required to separate an iron ore from the quartz or sand with which it is intermixed, as in the mineral employed by Stassano, and of which there are many varieties all over the world. Such an operation is one of great simplicity and possesses no elements of complication, the quartz being absolutely non-magnetic and the iron product either strongly magnetic or may readily be made so. But when we come to such products as spathic-iron blende or pyritic blende, it will be found that there are many points to be investigated. Pure zinc blende is always non-magnetic; the samples examined by the author have yielded nothing to a strong magnetic current, either before or after roasting, but it is certain that varieties of this mineral exist, possessing some small degree of magnetic permeability. Indeed, Schnelle, in the discussion that followed his paper, (page 414), stated, "Pyritic blendes can be treated directly by the magnetic process if the blende possesses sufficient permeability to render its separation possible from the almost non-magnetic pyrites." Iron pyrites, either free from copper, or that containing but a few parts per cent., is non-magnetic, although a raw Rio Tinto specimen, carefully sized over a screen, will probably yield several parts per cent. of magnetic product to a magnetic flux of high density. A fairly pure raw copper pyrites (chalcopyrite) which contains from 30 per cent. to 34 per cent. of metallic copper is also absolutely non-magnetic, so that a pyritic blende will not be improved in quality by passing it over a magnetic separator in the raw state. It will not even be separated from the quartz that accompanies it, seeing that this also is non-magnetic. It has, however, already been shown that when either cupreous or non-cupreous pyrites are subjected to the action of heat the iron product is rendered magnetic, and this fact has been utilised in many of the installations for magnetic separation.

The term "roasting" as applied to mineral products usually signifies heating in a current of air, and when iron pyrites are thus treated the sulphur commences to burn at a temperature of about $450^{\circ}\text{C}.$, and a cinder is left consisting, in the main, of peroxide, together with some magnetic oxide of iron. Pyrites cinders are nearly always strongly magnetic, a fact which the student may readily verify for himself by the use of a small hand magnet.

But it has already been shown that it is not necessary to drive off the whole of the sulphur from pyrites in order to form a magnetic product, it being quite sufficient to convert the mineral into magnetic pyrites (Fe_7S_8), though it is probable that in actual practice, especially when air is present, the magnetic sulphide will be accompanied by magnetic oxide, with the liability also to the presence of soluble sulphates. It will there-

fore be seen that the operation of magnetically separating a pyritic blende depends quite as much upon chemical methods as upon those that are strictly magnetic. In Schnelle's paper the result is given in detail of separating a pyritic blende (roasted) in the ring-type of machine illustrated by Fig. 204, and from those results we shall learn much of the practical possibilities of magnetic separation. It may be noted that the machine was but 18 inches in diameter, and yet was able to deal with more than one ton of roasted material per hour. The following table gives these results, together with the size of the particles operated upon, which is an important consideration.

TABLE 47.

SHOWING THE RESULTS OBTAINED BY A RING-TYPE MAGNETIC SEPARATOR.
(AFTER SCHNELLE.)

	Size of Grain. m.m	Quantity Kilos. per hour.	Magnetic.		Non-magnetic.		Yield of original Zinc. %
			Weight %.	% Zn.	Weight. %.	% Zn.	
I.	4.0—2.4	1000	10.18	6.1	20.11	48.5	94.01
II.	2.4—1.2	1050	13.23	6.5	19.82	52.6	92.37
III.	1.2—0.6	1000	5.34	5.7	8.84	53.1	93.91
IV.	0.6—0	400	8.05	6.5	14.43	47.3	92.86
Totals, etc.			36.80	6.27	63.20	50.15	93.21

The figures in the foregoing table show us that when operating upon a roasted pyritic blende the magnets withdrew 36.8 per cent. of the mineral, leaving 63.2 per cent. unacted upon. This non-magnetic portion contained 93.21 per cent. of the original zinc. A closer examination of the figures, however, teaches us more than this. It will be seen that the magnetic portion contained 6.27 per cent. of zinc, and the question arises, how did this come to be taken off with the magnetic product? Several explanations are possible. It may be that some of the particles submitted to treatment consisted of fragments of the magnetic product attached to the fragments of blende, causing the latter to respond to the influence of the magnet. It may also be imagined that some of the blende particles possessed a small degree of magnetic permeability, and so were carried away with the more strongly magnetic product through the influence of the intense current, which is more than probable; while a third explanation is possible, viz., mechanical adherence or "bunching," as it is technically termed. The first explanation also holds good for the presence of ferrous particles (non-magnetic) amongst the non-magnetic product, but there can be no mechanical adherence or bunching. As both the blende and the pyritic constituents are non-magnetic before being subjected to heat, it is only natural to suppose, that any particles that have escaped the influence of temperature will remain non-magnetic and will pass away with the quartz and blende. This is the

explanation of one form of incomplete separation. Another source of loss lies in the faulty adjustment of the partitions, when such are employed, allowing particles that have taken a definite direction under the influence of the magnets to fall where they were not intended to be deposited. It will thus be seen that the magnetic separation of minerals is a highly technical operation, and one demanding much knowledge both chemical and electrical. That this is so is proved by the many patents taken out for magnetic separators, and the few that are to be found in actual operation.

Pyritic blendes are to be found in several quarters of the globe, and when they contain copper (chalcopyrite) they should be valuable minerals, but until the introduction of magnetic separation such ores would scarcely pay the cost of raising, seeing that the zinc values were often lost. The new methods promise much in the direction of utilising these minerals, and, in the author's opinion, systematic methods of treatment will lead to good financial results, but such operations cannot be carried on haphazard with any chance of success.

The product of a mine well-known to the author is of a very perplexing character. It is a grit composed of blende, chalcopyrite, and several other substances in small quantity, in a matrix of quartz. The average ore raised contains 10 per cent. of copper and 30 per cent. of zinc, which, neglecting the minor constituents, would show it to consist of:—

Zinc blende (ZnS})	..	..	..	..	44.7	per cent.
Chalcopyrite ($\text{Cu}_2\text{S} \cdot \text{Fe}_2\text{S}_3$)	..	..	..	..	29.1	" "
Iron Sulphide (FeS})	..	..	..	..	2.3	" "
Quartz, etc.	..	..	..	..	23.9	" "

100.0

The iron sulphide appears to be evenly distributed throughout a great portion of the blende, as when this constituent can be obtained in a separate state it yields, after roasting, several parts per 100 of magnetic material which contains less than one per cent. of copper. Chalcopyrite contains 34 per cent. of copper. The chalcopyrite found in the mineral is not evenly distributed, but occurs in crystalline aggregations, which, though amounting to nearly one-third of the mass of the dressed ore, is yet so generally distributed as to be inseparable from the blende by the processes of cobbing and picking. The two metal values cannot be realised in the dressed ore, and the jigs and vanners only produce a more concentrated mixture of the chalcopyrite and the blende by washing away some of the quartz, the slimes being absolutely worthless though they contain a considerable percentage of copper.

The advantages of magnetic separation on a mineral of this kind are too patent to require description, so that some experiments made with this ore will not be found out of place here, giving, as they will do, much food for reflection to students of such matters. One of the advantages of magnetic separation is that the particles as a rule do not require to be very finely crushed. This may be seen by reference to Schnelle's table

(page 432) wherein it is shown that grains varying from 4.0 mm. to 2.4 mm. were separated with greater facility than those measuring from 1.2 mm. to 0.6 mm., and with much greater efficiency than particles sized from 0.6 mm. to dust. It is, of course, necessary to so crush a mineral that the particles shall be homogeneous in character and composition, but it must be remembered that the finer the mineral is crushed the greater difficulty there will be in the smelting operations afterwards; indeed, with very fine particles the operation of briquetting (see Vol. I., p. 516) will have to be seriously considered, while, if the ultimate object be to deal with the material by some chemical process, extreme divisibility will render leaching a slow operation. Then again, Schnelle's figures show us that the finest particles are not so readily acted upon by the magnetic flux, reducing the output and at the same time reducing the percentage yield from the original ore.

The mineral of which the proximate analysis has already been given was submitted to magnetic separation, the vanner product being taken as yielding particles ready for the separator without further reduction. These particles varied in size from the $\frac{3}{32}$ th of an inch to the $\frac{1}{32}$ th of an inch. They were passed over a magnetic separator capable of taking out 95 per cent. of Bessemer iron-dust from its admixture with sand, which shows that the machine was capable of dealing with the problem magnetically, the ore being roughly roasted to put the pyritic constituents into a condition of magnetic activity. The result of passing over the separator was to produce a magnetic portion containing 95 per cent. of the total copper, mixed with 36 per cent. of the total zinc originally present. The non-magnetic portion contained 62.5 per cent. of the total zinc, mixed with nearly 4.0 per cent. of the original copper, some small portion of each metal being lost by mechanical imperfections.

The magnetic portion was then passed through the machine again, substituting a weak current for the full force of the magnetic flux employed for the first separation; the portion so taken off containing 55 per cent. of the original copper with but 7.5 per cent. of the total zinc present in the original ore. In other words, the 479 parts of original magnetic product (see B, Table 48) containing 16.3 per cent. of copper, yielded 178 parts of a product containing 25.6 per cent. of copper and 10.7 per cent. of zinc. The magnetic flux was then slightly increased in density, and the residue from D brought under its influence, with the result of attracting 84.5 parts of a product containing 15.0 per cent. of the original copper and 7.3 per cent. of the zinc, the product itself, E, containing 14.5 per cent. of copper and 22.0 per cent. of zinc. The residue from E was next submitted to a further increased density of magnetic flux, and this fourth treatment withdrew 56.5 parts of a product representing 10.5 per cent. of the original copper and 5.0 per cent. of the original zinc, the fraction (F) containing 15.13 per cent. of copper and 22.5 per cent. of zinc. The residue from the fourth treatment contained 7.31 per cent. of copper and 24.9 per cent. of zinc, which represented about 15.0 per cent. respectively of each metal present in the original ore. These results have been collected in Table 48.

TABLE 48.

SHOWING THE RESULT OF PASSING A CHALCO-PYRITIC BLENDE THROUGH A
MAGNETIC SEPARATOR.

	Weight of Fraction	Copper in Magnetic portion.		Zinc in Non-magnetic.		Percent. of Metals.	
		%	Grms.	%	Grms.	Cu	Zn
A—Original Ore	860.0	9.54	82.0	29.3	252.0	100	100
B—Magnetic	479.0	16.30	78.0	18.9	90.2	95.1	35.8
C—Non-magnetic	380.0	0.76	2.9	41.5	157.7	3.5	62.5
D—2nd treatment of B	178.0	25.60	45.5	10.7	19.0	55.5	7.5
E—3rd " "	84.5	14.50	12.3	22.0	18.6	15.0	7.3
F—4th " "	56.5	15.13	8.6	22.5	12.7	10.5	5.0
G—Residue from F	160.0	7.31	11.7	24.9	39.8	14.2	15.8

The foregoing products were submitted to the author for analysis, but they were exhaustively examined by other methods, in order to discover if possible why particles of blende should always accompany the magnetic product. With respect to the presence of copper always to be found in the non-magnetic portion, a microscopical examination revealed unmistakably the existence of unaltered chalcopyrite, so that when the product was again heated, these particles could be withdrawn from the field of view by an ordinary hand-magnet, a chemical analysis then showing that the copper contents had been withdrawn. This points to the necessity of carefully subjecting the mineral to the action of heat so that all the particles are uniformly affected. The microscope, also revealed the fact that the bulk of the blende particles were black and opaque, though some of them were yellowish brown and transparent, and many of them possessed a surface layer of chalcopyrites which resulted from the imperfect detachment of the pyritic crystals from the blende mass during the process of crushing. The blende particles though black and opaque were for the greatest part non-magnetic, and the chalcopyritic particles were clean and homogeneous, but the former being more or less soiled by the adhering magnetic particles (altered chalcopyrites) was strongly or feebly magnetic according to the extent of the contamination. This accounted for the presence of zinc in the magnetic portion. It was further found, that in the majority of cases, but one face of the blende particle was coated with the contaminating chalcopyrites, so it is quite possible that a finer crushing of such portions may not be of much service, while, on the other hand, a surface attrition might enable the magnetic portion to be separated by screening or by another run through the machine. In the microscopical examination of the samples it was noticed that the magnetic particles smaller than the one-sixtieth of an inch in size had become self-magnets, that they adhered to each other in polar order, forming chains of ten or a dozen particles, or more, and these in their convolutions, often held much larger particles of feebly magnetic blende in imprisonment. This was not noticed in

magnetic particles larger than the one-thirtieth of an inch. The magnetic particles smaller than the one-ninetieth of an inch seemed in every case to have become self-magnets, and the tendency to assume this state decreased as the particles increased in size.

Realising that the microscope had been of service in offering a probable explanation of some of the difficulties of magnetic separation, the investigation was continued upon lines tending to eliminate some of the errors of the aforesaid trials. The first step was to critically compare the mixed mineral with a sample of the pure blende vein from the same mine, which had been found absolutely non-magnetic. Under the microscope the difference between the two blendes was unmistakable, the non-magnetic blende, even after subjection to heat, was clear and semi-transparent, while the feebly magnetic blende, occurring in the mixed mineral, was of a dull, opaque black. In order to avoid any complication arising from the presence of oxides, the product was heated to dull redness in a closed scorifier, which was not opened until the contents had cooled down to the temperature of the atmosphere. It was found that if the temperature employed was too high, there was a tendency to fusion, and so, to avoid errors, all roasts were rejected that showed even a tendency to caking. The product thus prepared was carefully sized by passing it through sieves of 30, 60 and 90 wires to the lineal inch, the fractions thus separated being styled A, B, C and D; fraction A remaining on the 30-mesh sieve, while D was that portion passing through the sieve of 90-mesh. The composition of these fractions may be seen in the following table :—

TABLE 49.
COMPOSITION OF CHALCOPYRITIC BLENDE.

	Weight.	Size. Inch.	Cu.	Fe.	Zn.	
A	157	$\frac{1}{16}$ — $\frac{1}{8}$	16.6	15.5	25.7	Fraction A proved to be too coarse for the machine.
B	525	$\frac{1}{8}$ — $\frac{1}{4}$	13.7	13.2	28.9	
C	258	$\frac{1}{4}$ — $\frac{1}{2}$	10.9	10.8	26.5	
D	342	$\frac{1}{2}$ — $\frac{3}{8}$	9.1	9.1	25.4	

The average of the whole of the fractions shown in the table, when mixed, was 12.3 per cent. of copper and 27.1 per cent. of zinc. These carefully sized products were now submitted to magnetic separation, and the results may be found in Table 50, with the exception of Fraction A, which, as already stated, was found to be too coarse for the machine, without structural alteration.

The presence of a chalcopyritic coating upon the blende particles makes it quite clear that this is the disturbing element in the separation, but it will also be evident that some other explanation must be found for the presence of copper in the zinc portion when the proportion of chalcopyrites present as the adventitious coating is but infinitesimal. The true explanation has already been given—unroasted chalcopyrites is absolutely

non-magnetic, and if particles should have escaped the action of heat, no amount of magnetic density will separate it from its admixture with a non-magnetic blende.

TABLE 50.

SHOWING THE COMPOSITION OF MAGNETICALLY SEPARATED
CHALCOPYRITIC BLENDE:

	Metals in one hundred parts of each fraction.		Proportion of each metal to the total originally present.	
	Cu.	Zn.	Cu %.	Zn %.
<i>Magnetic—</i>				
A	—	—	—	—
B	30·6	7·9	71·5	8·4
C	29·8	10·1	76·5	10·6
D	26·8	10·5	80·1	11·2
<i>Non-magnetic</i>				
A	—	—	—	—
B	5·36	38·3	26·5	89·9
C	3·5	32·7	23·1	89·0
D	2·4	30·0	19·1	86·0

The magnetic portion from the sample B was separated into two portions by means of a weaker magnetic flux, and by this operation a fraction was taken off containing 33·7 per cent. of copper and 4·9 per cent. of zinc, this representing 54·2 per cent. of the total copper in the original ore and 3·7 per cent. of the total zinc, the remaining portion containing 23·7 per cent. of copper and 13·7 per cent. of zinc, or 17·3 per cent. of the total copper and 4·7 per cent. of the zinc. The more strongly magnetic product would be a valuable commercial article, but the decreased value of the feebly magnetic fraction, together with the high cupreous nature of the zinc product, would render the process too wasteful to be of much practical value, if it could not be improved.

The non-magnetic portion of B containing such a large proportion of the total copper was examined for soluble sulphates, but these were found to be absent. It was then examined for the oxides of copper and zinc, which were found to be present in small quantity, but not sufficient to account for the high copper contents of the fraction. After treatment with very dilute acid at 80° C., the surfaces of the particles were so cleaned as to greatly facilitate a microscopical examination. It was then seen clearly that the blende particles were, as already described, of two qualities, one of a clear resinoid appearance—clear yellowish-brown, while the other was opaque and black. The former was nearly pure blende, absolutely non-magnetic, while the black opaque particles were both non-magnetic and feebly magnetic. A quantity of the black opaque particles was then picked out under the microscope from the mixture of quartz and doubtful particles—a tedious

operation, seeing that their dimensions averaged about the 1-50th of an inch—but 0.787 gramme was so picked out, and under a dissecting lens of 5 diameters amplification the particles appeared to be as homogeneous as could be wished for. However, an examination under a power of 40 diameters disclosed the presence of a coating of altered chalcopyritic particles upon a face of a portion of the particles, while the remainder appeared to be absolutely free from this contamination, so it appeared probable that a magnet of high flux density would still separate the sample into two distinct portions. This operation was performed by a strong hand magnet, with the result of withdrawing 0.087 gramme, leaving behind 0.7 gramme, upon which the magnet had no action whatever. The results of the analysis of these two portions are very instructive:—

	Magnetic.	Non-magnetic.
Copper	5.3	0.75
Iron	6.4	2.40
Zinc	53.4	63.05
Sulphur	—	32.30
Silica	—	1.00
		<hr/> 99.50

The foregoing figures show conclusively that none of the sulphur of the blende was driven off by the magnetic roast; that the chalcopyrites present in the non-magnetic portion was less than 2.2 per cent., while the quantity necessary to make the particles feebly magnetic was 15.3 per cent. The analysis also shows that the black colour of the blende was due to the monosulphide of iron (FeS) which was present to the extent of 2.73 per cent. and which is not magnetic.

The conclusions to be drawn from such experiments as the foregoing are obvious. It is possible upon the commercial scale to separate from such minerals (1) a strongly magnetic portion of good value; (2) a non-magnetic portion of good value, leaving an intermediate fraction; (3) to be dealt with according to its chemical composition. In this case, the fractions would be approximately:—

- (1) Magnetic.—Cu. 33.7%; Zn. 4.9%.
- (2) Non-magnetic.—Zn. 46.4%; Cu. 1.3%.
- (3) Intermediate.—Cu. 14.5%; Zn. 25.5%.

Whether the intermediate portion can be separated further by more careful magnetic treatment or by any other process must always depend upon its chemical composition, but the fact that the type of machine employed must always be considered as an important factor in the operation is a point to which sufficient attention should be paid.

The problem of the treatment of any intermediate portion of a mineral, resulting from magnetic separation, is one which can only be solved after a careful investigation of its physical characteristics, in which the microscopical examination may prove invaluable. If the particles consist, in the main, of non-magnetic material, with loosely adhering fragments of magnetic material coating their surfaces, it is probable that a slight

attrition of the particles, caused by allowing them to roll over each other in a revolving drum, would wear off the surface of magnetic material, and so produce a magnetic dust on the one hand, and non-magnetic granules on the other, but much would depend upon the relative hardness of the two materials, though it is quite certain that the outside coating must, in the very nature of things, be worn away before the interior of the particle is exposed. In such a case, it would probably be found that the detritus would consist of both magnetic and non-magnetic substance, but if it were produced merely as a fraction of the original intermediate product, leaving the non-magnetic substance as a saleable article, a great deal would have been accomplished.

If, however, the magnetic material occurs intimately mixed with the non-magnetic substance in the intermediate portion coming from the magnetic separator, there seems to be no course open but to treat the fraction by some chemical process which will withdraw the valuable constituents from those that are valueless. An opportunity is here offered for the adoption of such a process as that described by Gin (page 363) or any similar operation conducted on the same lines. A mixture of chalcopyrites and zinc blende when carefully roasted at a suitable temperature will produce the sulphates of copper, iron and zinc, and if the operations be conducted as described by Gin, it should be possible to obtain a fairly good separation of these sulphates. These are, however, operations for which no definite instructions can be laid down beforehand, and a certain amount of preliminary work must be done before a successful process can even be foreshadowed. But various experimenters have recorded the results of their investigations upon the solubility of many compounds at both high and low temperatures which will stand the practical chemist in good stead when he is brought face to face with the need for such operations. Much information may be found in M. Etard's researches upon the solubility of salts in water at temperatures considerably above 100° C., and it remains for the Chemical Engineer to devise apparatus in which the results of these researches may be practically utilised.

Though such operations as the foregoing can scarcely be recognised as coming within the pale of magnetic separation, they are so intimately associated with its practical success as to make their study a necessity, as, when dealing with a material such as that described at (3) page 438, it would obviously be the reverse of economical, to discard a fraction containing so large a percentage of valuable metals. If by any operation the percentage of such intermediate portions can be reduced to a minimum, even by repeated magnetic treatment, it may probably be the least loss to neglect the value of one of the constituents, in which case the efforts of the experimenter should be directed to the problem of making this loss a minimum.

As an illustration of the separation capable of being performed by the adherence type of machine, some figures may be given from the Knowles "New Century" magnetic separator (Fig. 208), showing its effect upon zinc-iron concentrates from the Wilfley concentrating tables of the

Daly-Judge Mining Co. at Utah. One hundred and fifty-five pounds of the concentrates were passed through a 60-mesh screen and given a slight magnetic roast, when upon passing through the magnetic separator it was resolved into the following products :—

TABLE 51.

SHOWING THE RESULTS OBTAINED WITH A KNOWLES MAGNETIC SEPARATOR.

	Weight. Lbs.	Percentage composition.		Percentage recovery of original metals.	
		Zinc.	Iron.	Zinc.	Iron.
Original ore	..	43'20	11'20	100	100
Zinc portion	114	55'65	1'12	96'0	7'0
Middlings	8	24'94	31'48	1'8	14'8
Iron portion	30	3'53	44'05	1'6	77'6

Here again we find an intermediate portion to deal with besides the two main products, a problem which perhaps will exercise as much ingenuity as in the case of the pyritic blende just illustrated.

Many other applications of electricity to chemical processes on the manufacturing scale will no doubt present themselves to the reader, but enough has already been said to show the importance of a careful study of electrical methods generally. They are of comparatively recent introduction, are proving a veritable handmaid to chemistry, and the importance of their development should not be overlooked.

CHAPTER VII.

THE CONSTRUCTION OF PACKAGES.

It may, on first thought, be considered that the construction of packages would hardly come within the purview of chemical engineering, but when it is known what a very large percentage of the total cost of some finished articles lies in the package, it will be readily seen that this is a subject that must be taken into consideration in any establishment that has made up its mind to be permanent.

Sacks and bags were at one time very sparingly employed in the heavy chemical industry, their use being almost entirely confined to nitrate of soda and sulphate of ammonia, but nowadays there seems a disposition to extend their utility, and they are brought in for soda-ash, crystals of various kinds, salt-cake, and other chemicals of a like nature. The bags that are now used for packing ammonia-soda cost about £18 per 100 tons of alkali, and it is usual to reckon upon such bags costing 4½d. apiece. Sulphate of ammonia is usually packed in second-hand bags. As a rule, a chemical manufacturer seldom buys anything new that is purchasable at second-hand, and in the matter of bags perhaps he is right, as his liability often ceases at his works, and beyond that point he has no control over the conditions of transit. New bags are made from jute sacking, and there are several ingenious machines for making them, some of which may be seen working in Dundee. An ordinary sized bag for chemical purposes will hold about 2 cwts. of salt-cake or sulphate of ammonia, and, according to its quality, will cost from 2½d. to 8d. each. Bags should be manipulated under cranes with slings only, and if the carriers are found to employ hooks, a claim for damage should be made at once. For filling sacks, a sack-holder is required, as otherwise one or two men (generally two) are occupied in keeping the mouth open. The best sack-holder is that made by Mr. Richard Simon, of Nottingham, two forms of which may be seen in Figs. 209 and 210. The machine in actual operation is shown by Fig. 211, from which it may be gathered that the sack is easily secured with the mouth held wide open, and when filled may be instantly released, slipping on to a truck that may be placed underneath it. With this appliance, one man, or a strong youth, can fill and wheel away more material than two men can do, when the sack has to be held open and the material filled off the floor.

The carboy and its hamper have been sufficiently described at page 404 of Vol. I., so that it is unnecessary to go further into details respecting it. A few words may be added, however, to say that carboys containing

acids and other corrosive liquids are often packed in half-petroleums, cut horizontally. The carboy is first packed in one half and then the top of the carboy is securely wound round with hay-bands or straw rope upon which a heap of loose hay is placed. Over all this is put the other half of the barrel, and this is firmly secured in its place in any convenient manner. For the carriage of carboys by rail attention must be again directed to Fig. 181, p. 404, of Vol. I.

Iron and steel drums have already been sufficiently described, but there is a word of warning that may well be given here. It is in the direction of strength. Railway rates, and, in fact, all other carrying charges, are determined by the gross weight, and so the tendency has been in many works to reduce the weight of both iron and steel drums, in some instances with



FIG. 200.—SIMON'S SACK-HOLDER.
(Non-adjustable).

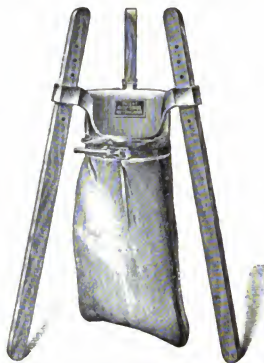


FIG. 210.—SIMON'S SACK-HOLDER.
(Adjustable).

disastrous results. Only a short time ago the author was called in to value the plant and materials of a certain chemical works, and found a large shed filled with thin steel drums all in an utter state of collapse owing to having been ordered too weak to withstand the wear and tear of more than *two* railway journeys. Such a purchase must always be a serious loss to any manufacturing establishment, and it should further be remembered that if much capital be expended in the package department, it will require even more careful supervision and constant inspection than the manufacturing department. Many firms have made profits in their manufacturing and lost them in the expected return of empty packages. How often has an acid maker sent out a lurry load of good sound hampers and carboys to find them returned as a broken, miserable lot, fit only for the scrap heap? And he fancies he dare not complain, owing to the competition of a neighbouring

manufacturer, who will be served in exactly the same manner when his time comes.

Much more will have to be done in the future in the way of popularising the use of chemical substances at home. Many things can be put up in tins or canisters, or small kegs, such as paint, soft soap, or the aniline colours are put up in ; but in order that this may be done successfully it is necessary that the boxes, canisters, kegs or drums should be made by the chemical manufacturer himself. This has for many years been a large industry in America, where tins are made for the "canning" industries in immense numbers, and the machinery for this purpose is very ingenious.



FIG. 211—SACK-HOLDER IN USE.

It is pleasing, however, to note that England has always been to the front in the manufacture of machinery for making sheet metal receptacles, and the firm of Messrs. J. Rhodes & Sons, of Wakefield, who for three-quarters of a century have been engaged in making machinery for sheet-metal working may be specially mentioned. In order to give the reader some idea of the method of making canisters, etc., reference must be made to Fig. 212, which represents an adjustable power press for stamping out the tops and bottoms of tin canisters.

The foregoing machine is constructed in about eight sizes. The tops and bottoms are produced by combination dies worked in the above press, and are cut out and formed at one blow, and any lettering required is also embossed on the covers at the same operation, the production being at the rate of seventy gross per day of ten hours. As these machines are worked by boys and girls at this rapid rate, Messrs. Rhodes have recently patented a safety device to prevent accidents to the children's fingers. The bodies of canisters are either cut by dies working in power presses, similar to the above, or by treadle shears. They are then formed to shape on small rollers if round, or by other machines if oval or rectangular. The bodies, after the edges have been "hooked" in a small bench machine, are then "grooved" or fastened together in a grooving press shown in Fig. 213.



FIG. 212.
ADJUSTABLE POWER
PRESS.



FIG. 213.
GROOVING PRESS.



FIG. 214.
DOUBLE SEAMING
MACHINE.

The tops and bottoms are then either "crimped" or "double-seamed" on to the bodies. Double-seaming, or "double-locking" as it is technically called, is the most substantial manner of making the joint, and the latest type of machine for performing this operation is shown in Fig. 214, which will fasten on both top and bottom (or one end only if desired), at one turn of the hand lever.

The cutting and drawing press shown by Fig. 215 is employed for cutting and pressing to shape at one operation the ends of round drums. They are used by all the leading drum-makers in this country, while Fig. 216 shows a specially designed machine for rapidly grooving or fastening together the body seams of drums or kegs, and which does away with the old-fashioned method of rivetting.

As a reference to American machinery, Fig. 217 is given. It is an automatic can-body forming machine, used for making the bodies of tins, either round, square, oblong, or oval, according to the forming tools used

The body-blank is cut in a small press and placed on the table of the machine when the operations of body-forming, viz., side seaming, locking, and closing down are automatically carried out at the rate of about one in every second.

At this point, several appliances in practical use for packetting goods and for wrapping tablets deserve a little more than passing notice. The packetting machines made by Messrs. Job Day and Sons, of Garden Lane, Leeds, and shown by Fig. 218, are in reality three separate machines, the first making an open bag, the second a measuring machine, while the third is the packetting machine proper. The illustration shows the full set of machines in operation. The first, or open bag machine, takes the paper from a roll or rolls, and the paper passing under the guillotine is cut to size and carried to the forming box, the bag being then folded and delivered on to a table. The measuring machine, which is adjustable for different quantities of material

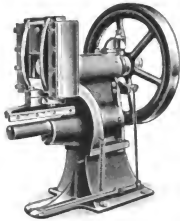


FIG. 215.
CUTTING AND DRAWING PRESS.

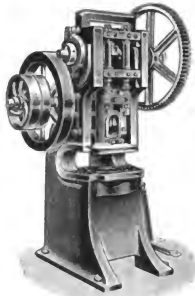


FIG. 216.
DRUM GROOVING MACHINE.

as required, automatically measures the charge which is placed in the open bag of the packetting machine by passing down a shute, kept vibrating in order that the material is readily discharged therefrom. This packetting machine, or, as it is sometimes called, the folding machine, contains a series of movable moulds, into which the open bag is placed, and as it passes under the shute of the measuring machine it receives a series of motions tending to consolidate the charge within it, after which the packets are folded and conveyed away upon a travelling belt. These machines can be worked separately, or in conjunction with each other, and attain a speed up to 27 packets per minute with one attendant, on various sizes, shapes, and weights of packet.

The wrapping machine made by the Forgrove Machinery Co., Ltd., of Leeds, is shown in Fig. 219, and is specially designed for wrapping tablets, small card-board boxes, or anything of a similar nature, as black-lead, tablet blue, soap, and many other articles too numerous to mention. The tablets

to be wrapped are fed into a hopper, and the sheets for wrapping are either fed from a roll, or in the case of tin foil, placed in a tray. The sheets and tablets are brought together automatically, and the wrapped blocks are continuously discharged from the chute of the machine. Single machines will wrap from 5,000 to 7,000 tablets per hour, one horse-power being sufficient to drive eight machines. The average speed of hand wrapping is eight tablets per minute, whereas the speed of this machine is 100 per minute, with a further considerable economy in the use of paper and tinfoil.

We must now come to the question of casks and barrels, which, as already stated, is no unimportant item in the cost of selling heavy chemicals.

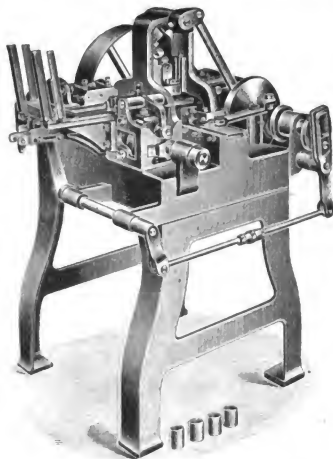


FIG. 217.—AUTOMATIC CAN-BODY FORMING MACHINE.

It may not have been generally appreciated, but it was nevertheless a fact, that when bleaching powder was selling at £3 15s. per ton, the cost of the casks containing it was no less than 16s. when made by hand, as was done in most works. In 1894 the cost of packing bleach at the works of the Northumbrian Chemical Company was 16s. 6d. per ton, while some figures given to the author in November, 1895, showed that the cost of casking bleach to such a large firm as the United Alkali Company was not below 15s.

A very great deal of the casking done in the heavy chemical trade was formerly in old or second-hand casks. The hard wood casks were once-used sugar tierces, but when the Demerara sugar trade was ousted by that of the

Continental beet-sugar, there was no considerable quantity of tierces finding their way to England, and at the same time there was likewise no demand abroad for the materials from which to make hardwood casks, so that

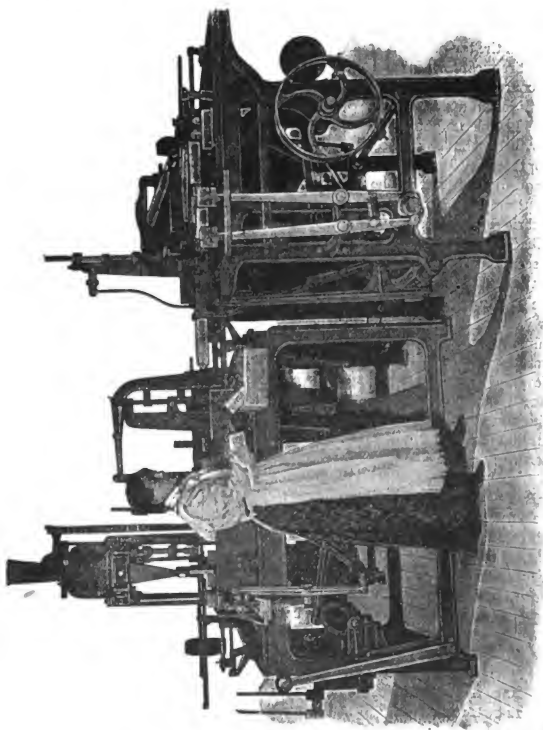


FIG. 218.—DAY'S AUTOMATIC PACKETTING MACHINE.

by-and-by bundles of hard wood staves found their way into this country, under the name of "shooks." These were purchased in Liverpool, and made up to form hard wood casks. A shook was value for 4s. 10½d., and made

a cask holding about 13 cwts. of bleaching powder. Hard wood casks of other dimensions are sometimes made of other material. Old petroleum casks were at one time purchasable at half-a-crown apiece, though the price subsequently rose to above four shillings. These held three cwts. of bleach, and by adding to the number of staves in the barrel, they were often enlarged to hold from 5 cwts. to 6 cwts.

In the tar-products trade, pipes, puncheons, and petroleum barrels are in great request for the carriage of benzol, naphthas, and carbolic acid. These, of course, must be absolutely tight, and for such products as benzol, perfectly clean inside.

Petroleum barrels, pipes, and puncheons, have now been largely displaced by barrels and drums made of sheet steel. Those made by the Steel Barrel Co., Ltd., of Uxbridge, have already been described on page 406 of Vol. I., and it seems scarcely necessary to add that these casks are employed for the packing of solid substances as well as for liquids. The machinery for making these casks scarcely comes within the purview of this chapter, as their manufacture is a speciality which does not allow of introduction into a small establishment.

In the packing of solid materials, such as bleaching powder, the cost per ton will vary with the size of the cask and its method of construction. Bleaching powder weighs about 50 lbs. to the cubic foot, and from this the capacity and cost of packing may be found from the following experiences of the author with hand-made casks :—

7 cwt. to 8 cwt. soft woods,	11/6½	per ton,	5/8 in. staves.
10 cwt. to 12 cwt. „	13/6	„	¾ in. staves.
10 cwt. to 12 cwt. hard woods,	17/10	„	shooks, 5/.
12 cwt. to 14 cwt. „	16/8	„	shooks.
* 5 cwt. to 6 cwt. enlarged petroleum,	27/5	„	old petroleum.
3 cwt. old petroleum	29/3	„	„ 4/3.
2½ cwt. lard barrels	29/6	„	old lard barrels, 4/.

The above costs include all expenses from the unloading of the staves and hoops from the railway wagon or boat, as the case may be, to the delivery

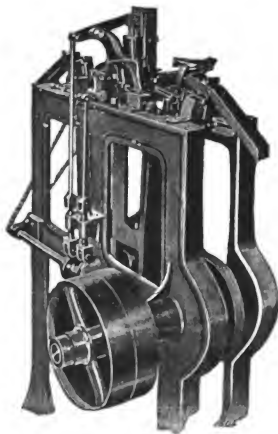


FIG. 219—WRAPPING MACHINE.

of the finished cask at the door of the cooperage. It includes the "heading-up" after filling and the subsequent tightening of the hoops before shipping, but does not include weighing, marking or loading.

In July, 1897, the cost of making hardwood casks for bleach at Northwich, was as follows :—

					A.		B.	
					10/12 cwt.s.		12/14 cwt.s.	
					s. d.		s. d.	
1	shook	..	..	..	5	0	..	5 3
2	32 in. heads	..	..	..	1	3	..	—
2	34 in. heads	..	..	..	—	..	1	6
10	wood hoops, 11 ft.	..	..	..	0	6	..	—
10	" " 12 ft.	..	..	..	—	..	0	8
4	" " 9 ft.	..	..	..	0	2	..	0 2
2	iron hoops	..	..	..	0	3	..	0 3
	Nails and yarn	..	..	..	0	2	..	0 2
	Cooper, for making	..	..	..	1	7	..	1 9
	" heading and tightening	..	..	..	0	1	..	0 1
	Wear on tools, truss hoops, etc.	..	..	..	0	6	..	0 6
					9 6		..	10 4

Ten tons of bleach required nineteen of the A casks, or sixteen casks of B.

Small casks or kegs, such as are used for chlorate of potash, or soda crystals, or many other substances of similar nature, are made of 27 inch staves and six feet hoops. These will hold 2 cwt.s. of soda crystals, but for these small sizes the merits of the Guelph cask are pre-eminent. The Guelph cask is shown in Fig. 220, and it may be as well to add that the Guelph Company also supply machines to large users of these casks, so that they may be made on the spot.

Straight-sawn fir staves are used almost exclusively for the commoner descriptions of slack barrels for holding soda ash, cement, and other chemicals—while straight-sawn staves of the harder woods, beech, birch, elm, oak and ash, are employed for tallow casks, and small kegs and barrels for holding vinegar, paints, white-lead, soft soap, gunpowder, and the like. Riven staves are used exclusively for wet casks, while petroleum barrels are made from staves cut with a cylindrical saw, which cuts the staves sectionally to the approximate curve which they will have when made up into the cask.

Fir staves cost about £5 7s. 6d. per standard, f.o.r. at Garston, which price is equal to (the stave being 44 ins. \times $\frac{3}{4}$ in.) 44s. 10d. per *mil.* of 1,200 pieces each 3 ins. wide. A "standard" weighs $2\frac{1}{2}$ tons, and about 33 staves will make an ordinary bleach cask.

The hoops are generally of two kinds, French and Dutch. The French are of chestnut, costing 47s. 6d. per 1,200, nine feet in length, or 55s. per 1,200 if ten feet lengths. The most usually employed are the Dutch, as they are cheaper, costing 43s. 6d. for nine feet and 48s. 6d. for ten feet. Truss hoops are part and parcel of the machinery for cask making. They are thick and

strong hoops covered with tarred string, costing from 2s. 6d. to 2s. 9d. each, according to diameter.

Straight sawn staves lend themselves admirably to cask making by simple machinery, and in order to show the general sequence of operations in making soda ash or bleach casks by this means, the author is indebted to Messrs. A. Ransome and Co., Ltd., of London and Newark, for a series of illustrations that will make the description more easily understood.



FIG. 220.—GURLYPH CASKS.

We will presume the ordinary straight-sawn fir staves to be used, 44 ins. by $\frac{1}{4}$ in., and that the heads are cut to parallel widths and thicknesses. The first operation would be to joint the staves on the machine shown by Fig. 221.

This machine joints the stave to any bilge required, which is regulated by the form of the travelling template shown upon the side of the machine, upon which the cutter block rises and falls. The machine is adapted for jointing straight-sawn staves of any sort of wood for tight, semi-tight, and slack casks; it works with great rapidity and will joint the staves for one hard wood cask in about one minute. It has been universally adopted by the Thames and Medway cement makers, who have a production of over 100,000 barrels per week.

The staves, jointed as above described, are next "set up" in the appliance shown in Fig. 222, in which a youth can set up a cask with the greatest accuracy in much less time than a cooper can raise one in the ordinary manner.

To set up a cask in this apparatus, the staves require merely to be arranged in a circle inside the hoops, the last one being selected of such a width that when forced into its place it wedges the whole firmly together. The cask is then carried to the trussing machine, such as is illustrated by Fig. 223, but there are several patterns of this appliance. The cask, being placed with its closed end downwards upon the rising table, is rapidly raised by simply moving a lever, the cask being pressed upwards so that the upper ends of the staves are gathered tightly together, and



FIG. 222.—
SETTING-UP APPARATUS.

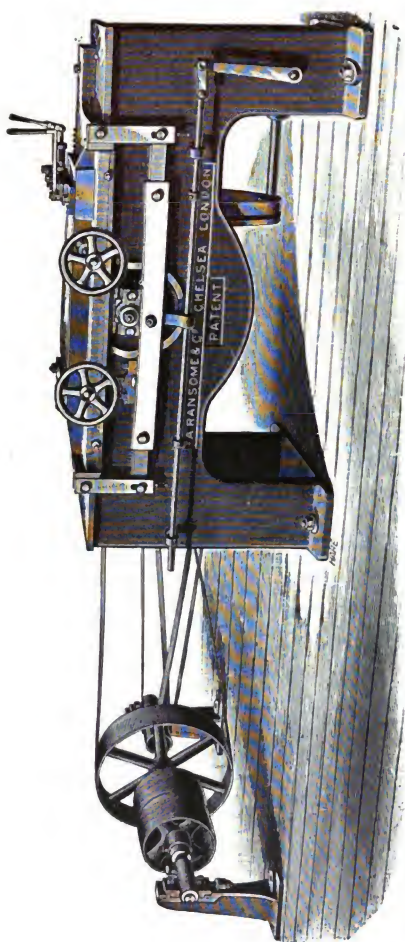


FIG. 221.— UNIVERSAL STAVE-JOINTING MACHINE.

forced in the truss hoops held in the cone. The cask being thus trussed at one end, in the truss hoops held in the cone, the latter is opened, and the cask brought out with two truss hoops forced tightly upon it.

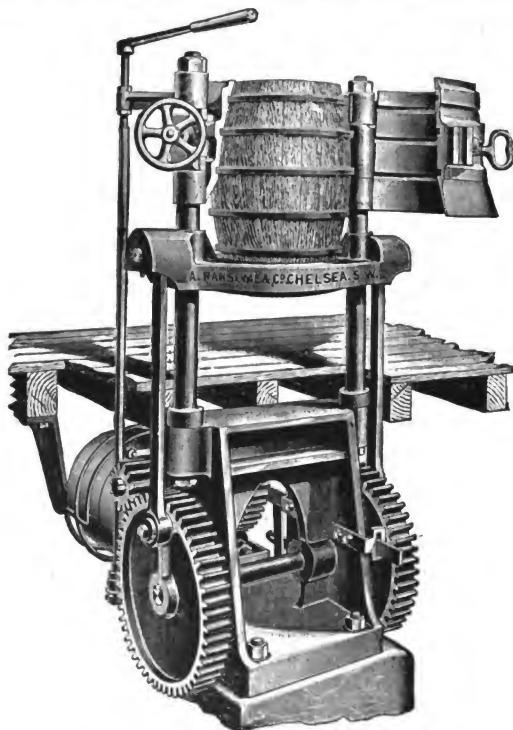


FIG. 223.—POWER CONE TRUSSING MACHINE.

It is then reversed, and three more truss hoops placed in the cone, when the second rising of the table completes the trussing. The illustration shows the cask in this stage completely trussed, and ready to be transferred to the machine that performs the next operation, viz., that of "chiming"

the cask at both ends simultaneously. The trussing machines are made of various sizes, each of which can be made to truss casks of smaller dimensions (within certain limits) by having exchange cones for each size.

The steaming or firing of the casks after they have been set up is not an unimportant matter. In all slack casks, firing is very generally adopted, and is usually an open circular grate standing on a square iron plate. In some trussing machines, a heated iron plate is placed near, and the staves having been previously heated by being laid for a few moments upon it with their inner face downwards, are set up on the table of the trussing machine at once, so that they are in position for that operation without requiring removal.

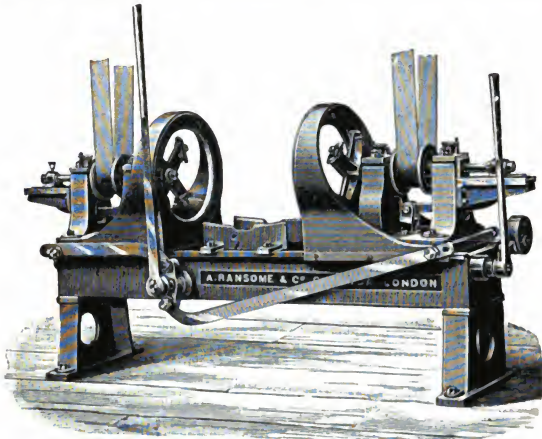


FIG. 224.—CHIMING MACHINE FOR SLACK CASKS.

In order to produce good casks, it is necessary to either joint up the staves so as to make a complete circle when they are set up, or otherwise to bring sufficient pressure to bear upon them so as to give them the required curve in the direction of their width. The extent to which a stave will bend in the direction of its width in trussing, depends not only upon its thickness, but also upon its width, and the quality of the wood of which it is made. Oak staves will bend very little in the trussing machine, while the soft wood staves for slack barrels, and also the thin staves of beech, birch, and elm, used for the lighter descriptions of semi-tight casks, will take almost the whole of the requisite curve in the machine. For this reason, fir staves require to be jointed without any bevel whatever, as the acquired curve

throws the joints into the correct radial line pointing to the centre of the cask. Leaving the trussing machine, the barrel is ready for the chiming machine shown by Fig. 224, in which both ends are trimmed off, and the cask is ready to receive the heads.

In the chiming machine, the cask, when laid on the bed, is instantaneously and correctly chucked by depressing the long lever at the front of the machine, which brings the chuck-plates towards each other, thus firmly clamping the cask between them. When in this position, the cutter discs revolving at a high speed are brought simultaneously into contact with the two ends of the cask by the lever shown in the engraving on the right hand side of the machine, neatly bevelling the ends of the staves for the reception of the heads. This has the effect of giving a finished appearance to the cask

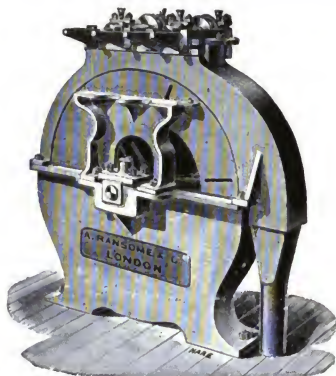


FIG. 225.—HEAD JOINTING AND DOWELLING MACHINE.

with a regularity unattainable by hand work. The output of a chiming machine, worked by one lad, is roughly 10,000 cement barrels per week, and it will always pay to put one down for an output of over 500 barrels weekly.

We now come to the operation of making the heads, which are produced in the machine shown in Fig. 225.

In this machine, which is chiefly used for the lighter descriptions of casks, the boards are jointed by being lightly pressed against the face of a revolving disc set with plane-irons, which instantaneously shoot the edge, leaving it true and smooth. The boring-bits work in a frame carried just above the top of the disc, so that as soon as the edges of a piece of heading are planed, the lad has merely to present them to the augers to complete it

ready for putting together. The auger spindles are adjustable laterally, so as to bore holes nearer to, or farther apart, and both the boring apparatus and planing disc are fitted with horizontal rests, upon which the board is held when being jointed or bored. The cutter disc is boxed in by an iron casing, and the draught generated by the rotation of the disc causes all the shavings made by the knives to be expelled through an aperture in the casing, to which a pipe is attached to conduct them away. A lad at this machine will joint and bore the heads for at least 400 casks in 10 hours, and the same machine will serve for heads of several sizes. Dowelled heads are, of course, only required in casks requiring water-tight joints, such as for liquids, semi-liquids

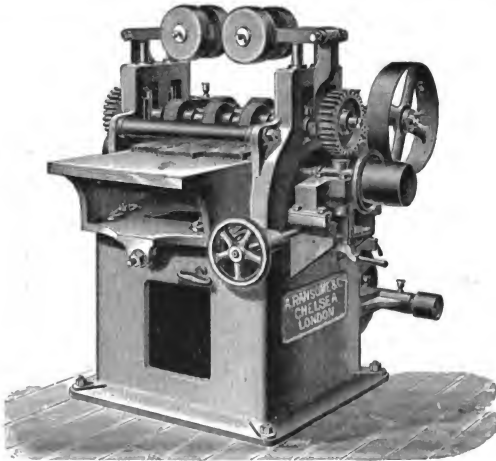


FIG. 226.—HEAD PLANING MACHINE.

or fine powders; for ordinary kegs, in which dry chemical crystals are to be packed, the making of the head does not require so much attention.

When a jointed up head requires planing, it is passed through a machine shown in Fig. 226.

This machine planes the heads of the casks after they have been dowelled together. It is very rapid in its action, planing as many as 700 to 800 heads per hour. The planing cutters are fitted to a revolving adze block running below the table. The spindle revolves in bearings fixed in a drawer in some forms of the machine, which can be withdrawn to facilitate sharpening, setting, or changing the cutters. The heads are fed over the cutter by a series of grooved rollers, which, at the same time, press them down to the cutter,

while the latter simply skims the under surface without unduly wasting the wood. It is only in certain descriptions of casks that this head-planing operation is necessary, but the description is given here as there is no telling how long it may be before the chemical trade will be compelled to make its own wet barrels as a substitute for petroleum.

The operation of planing being accomplished, the head is rounded and bevelled in the machine illustrated by Fig. 227, or in the case of heads that do not require a bevel, in the machine shown by Fig. 228, after which the head is ready for insertion in the cask.

This head-rounding machine (Fig. 227) is the most rapid and effective machine for dealing with the heads of soft-wood casks that require bevelling, but it is not so well suited for hard-wood heads. The head after being



FIG. 227. - HEAD ROUNDING AND BEVELLING MACHINE.

dowelled together is placed vertically between the two chucks, which remain stationary until the head is in position and firmly clamped by depressing the pedal on the right of the illustration. The same movement sets the chucks in motion by forcing a friction pad against another constantly revolving pad. The cutters are brought into action by the hand lever in front of the machine, and so easy is it to manipulate that after a little practice a boy should be able to chuck and turn out from six to ten heads per minute, according to size. By employing exchange chuck plates the same machine will serve for several sizes of heads.

Fig. 228 shows the head-rounding machine for slack casks. It is intended for rounding heads, the edges of which do not require bevelling, such as is the case with English cement barrels, and other forms of soft-wood casks, where, instead of being fitted into a groove or "croze," the heads are

held in position between wooden hoops, nailed on the inside of the cask. In this category may be placed the casks for nearly all heavy chemicals. With this machine, a pair of heads are turned simultaneously, the boards for each head being merely placed side by side upon the revolving horizontal face plate, and held fast by an upper plate armed with points which effectually prevent them from flying out of the chuck. The cutter is carried in a vertical slide, and is brought up to its work by depressing the hand lever shown in the engraving, while the cutter slide, being attached to a horizontal sliding carriage, can be worked either inwards or outwards, to suit heads of various diameters. One lad working this machine can turn the heads for 1,000 barrels of ordinary dimensions per day of ten hours.



FIG. 228. HEAD-ROUNDING MACHINE.

The cask is now finished, with the exception of putting on the permanent hoops, which is the only operation that requires hand labour. Generally, these hoops are made of wood, but when made of iron (hoop-iron) a pair of machines illustrated by Figs. 229 and 230 are used for bending, splaying and rivetting them.

The hoop-splaying and bending machine shown in the illustration will splay and bend about 12 hoops per minute. They are bent and splayed by being passed between two hard steel rollers, the lower of which is plain and the upper one fluted spirally. Both of these rollers are driven, but the top one, which is held down by pressure weights, has sufficient vertical play to permit iron hoops of various gauges being passed under it. The amount of pressure applied is regulated by the position of the weights on the levers at the back of the machine, and the required amount of splay is obtained by placing one of the weights at a greater distance from the fulcrum than the other.

The hoop rivetting machine, shown by Fig. 230, is designed to work in connection with the bending and splaying machine. As will be seen, it consists of an upright cast-iron standard, with a short horizontal spindle running in between well lubricated bearings. An eccentric is fitted on the projecting end of the spindle, which, revolving continually, causes the rivetting tool to reciprocate. The hoop after being lapped, with the rivet inserted, is simply placed under the tool, which in coming down, rivets it perfectly at one single stroke, leaving a rounder and stronger rivet head than it would be



FIG. 229.—
HOOP SPYLING AND BENDING MACHINE.

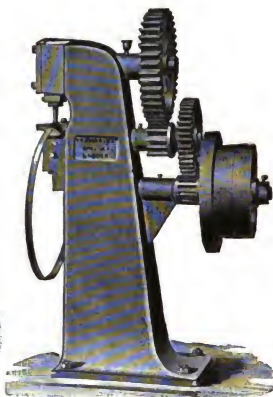


FIG. 230.—
HOOP RIVETTING MACHINE.

possible to make with a hammer. The output of this machine is very great, being determined by the aptitude of the boy working it, in picking up and lapping the hoops.

Thus ends the graphic account of cask making by machinery. The importance of the subject may be inferred from the fact that in England and America nearly one thousand patents have been taken out during the past one hundred years for improvements in cooperage machines. The importance of machines of this kind was well illustrated at the Inventions Exhibition in London in the year 1885, and at the Fisheries Exhibition two years previous, and it was the ingenious character of Messrs. Ransome's exhibits

at those exhibitions which tempted the author to give so full an account of their machines in the pages of this Handbook.

Before leaving this chapter, it is necessary to deal slightly with the construction of boxes and packing cases on the large scale. In the distribution of many chemical products, such, for instance, as baking powder, soap, disinfectants and many others, the material is not only packeted, but these packets are neatly enclosed in light wooden boxes, which are again enclosed in stronger boxes or cases for carriage by rail. It has already been pointed out that the cost of these boxes and packing cases forms a considerable item in a works cost sheet, the amount of which cannot be neglected, and it therefore behoves the manufacturer to see that this branch of the establishment is working upon the most economical lines. In the case of a small works, it may be wiser to purchase such boxes and cases from the wholesale maker of such articles, but in establishments of any magnitude, there is no doubt that the best course to adopt is to make the packing case department an integral portion of the works. The machinery necessary for this branch is both ingenious and special, and a description of it will show what little chance simple unaided hand labour has of competing against it.

The method of making light boxes with the special machinery of Messrs. A. Ransome and Co., Ltd., is to cut up the deals in what is known as an equilibrium deal or flitch frame shown in Fig. 231. These machines are furnished with two separate swing frames, worked from one double-throw crank shaft, which is so arranged that when one is at the top, the other is at the bottom of the stroke, and thus in ascending and descending they counter-balance each other, with the result that they can be driven much faster than an ordinary deal frame, and the necessity for a counterbalanced fly-wheel is obviated. Each swing frame is provided with a separate feed motion, which is a great advantage, as a deal on one side with two or three saws in it can be fed through at the fastest speed permissible, whereas the other side may be employed at the same time on hard wood, or with a larger number of saws at a slower rate of feed. The deals are fed through the frame by a roller feed, which is a patented speciality of the machine. Four double standards—not shown in the illustration—each fitted with two turned cast-iron rollers, are supplied with each frame, to carry the deals when passing through the machine. A No. 2 machine, to work with 24 saws, will weigh about four tons, and consumes about 8 H.P. in driving it at the normal speed of 320 revolutions per minute. The driving pulleys on the crank shaft are 30 ins. diameter with a 5 in. face.

For light boxes, as many as 15 boards may be cut from a 3-in. deal, but it is probable that 10 boards are as many as could be reckoned on for an economical production in constant work, and probably no class of box used for the purposes contemplated in this chapter would require to be made of thinner boards than 10 or 11 from a 3-in. deal.

The deals, having been cut into boards of the requisite thickness, are next cross-cut in the cross-cut saw-bench shown in Fig. 232 to the neat lengths required. The mode of working this bench is readily understood by inspecting the illustration. A strongly framed hard-wood table, sufficiently

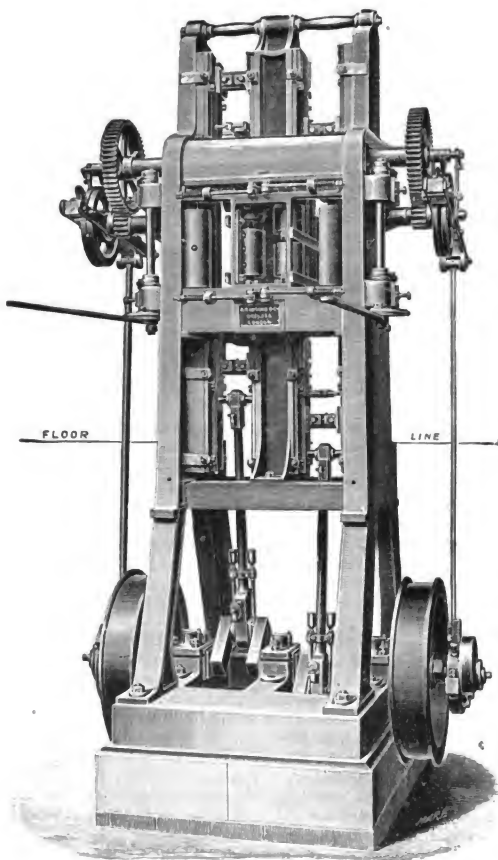


FIG. 231.—FRAZER'S EQUILIBRIUM DEAL FRAME.

long to enable pieces of considerable length being brought up to the saw in a true line, moves freely backwards and forwards upon turned wheels running

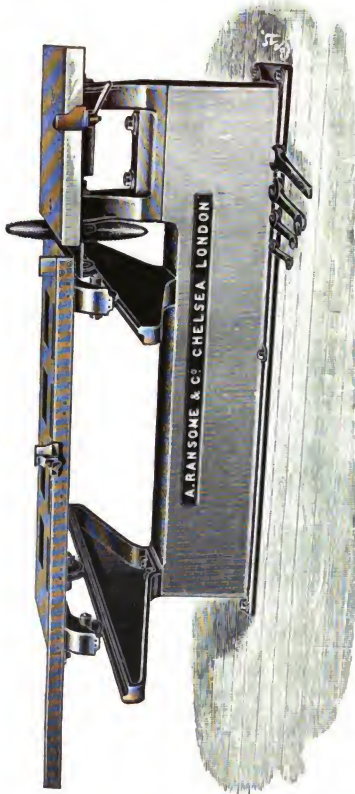


FIG. 232.—BOX-MAKERS' CROSS-CUT SAW-BENCH.

upon planed ways on the metal framing of the machine, the wheels nearest the saw being grooved to fit a V slide to prevent any side motion. The table is fitted with a long setting-out bar provided with a spring stop, which

can be set at any required position along it, so as to avoid the necessity of measuring and marking the wood beforehand. An adjustable fence is also provided to attach to the saw table in order that short pieces may be cut off to length.

The foregoing machine turns out smooth work on account of the great speed at which the saw is driven, and as the table moves in a direction exactly parallel to the plane in which the saw revolves the cuts are always square and true, so that for ordinary rough boxes the box boards are ready for putting together. Should a smooth surface be required, however, it will be necessary to run the boards through the planing machine shown by Fig. 233.

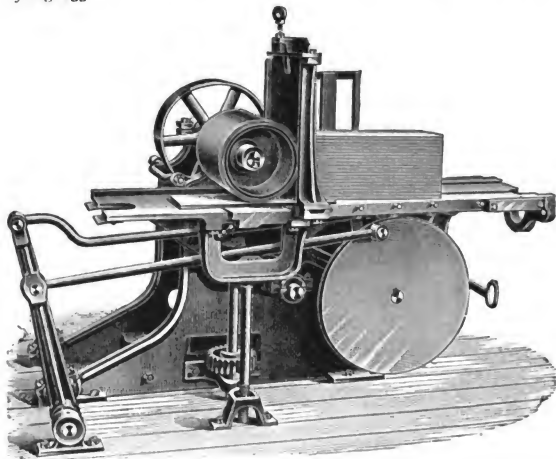


FIG. 233.—BOX-BOARD PLANING MACHINE.

If it be necessary to make a fancy box, or at least a good looking article, then the boards may be corner-locked, or, if a better joint be required, dove-tailed, while, if the box be a plain variety, the nailing may easily be effected by machinery. In the first instance, what is known as corner-locking was originally designed for the production of tea-boxes in India, and is a substitute for dove-tailing. It is found in practice that dove-tailing is exceedingly tedious when performed by hand or by machinery; it is either slow or complicated, or both, according to the class of dove-tail to be made, hence any rapid and inexpensive substitute for the process must be looked upon as a distinct advantage. Corner-locking has the effect of form-

ing a series of rectangular teeth and spaces of uniform dimensions along the edges of the boards forming the box, so that the teeth of one board can be readily fitted into the spaces of another. Theoretically, boards thus fitted have nothing to hold them together, save the friction occasioned by their engagement, but in practice it is found that by making them to fit tightly, they are to all intents and purposes as satisfactorily joined as if they were dove-tailed, as the warping and the swelling of the wood effectually cause

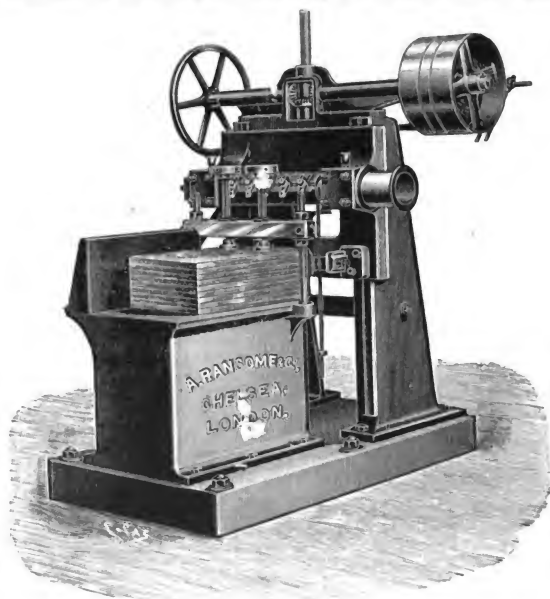


FIG. 234.—CORNER-LOCKING MACHINE.

them to hold together, and even if this were not sufficient, a little glue run into the corner of the box is all that is necessary.

The machine illustrated is composed in the main of a strong casting, upon the table of which the boards are piled to the depth of about one foot, and then clamped down. A cutter-block revolving between long gun-metal bearings having considerable range is fitted with a series of cutters, each one representing the size of the groove to be made. The vertical motion of the

slide is automatic, and is actuated by the long screw shown on the top of the machine. One downward motion of the slide completes the operation on one side of each of the boards clamped down, and after one end has been operated upon the boards are reversed and the process repeated. The machine will work with cutters of any size from half-an-inch upwards, and it is capable of taking in boards of any width, up to 19 inches. The weight of such a machine is about $2\frac{1}{2}$ tons, and it requires 2 H.P. to work it. The dove-tailing machine is shown in Fig. 235.

When the box is put together with nails, these are now inserted by a special machine, which even feeds them into the nail holders

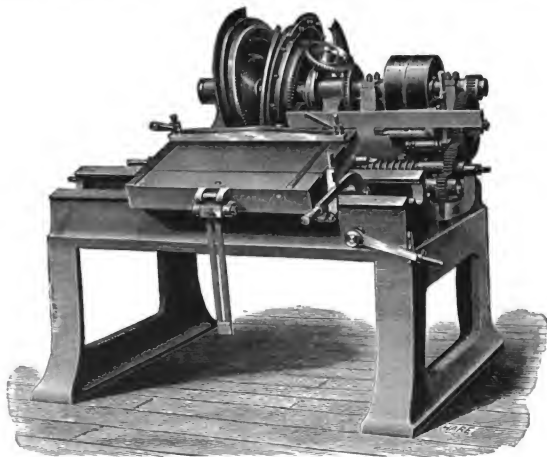


FIG. 235.—BOX-BOARD DOVETAILING MACHINE.

automatically. Such a machine is shown by Fig. 236, as used by the largest makers of soap boxes, chocolate boxes, mustard boxes, etc.

In this machine, which is arranged in different sizes, to drive a number of nails in at one time, boxes of any length may be dealt with, the small machines driving three nails at once, while the largest sizes will drive ten. The adjustments requisite to enable them to nail boxes of different sizes are easily and rapidly made. The boards of which the boxes are made are set up and rigidly clamped, while being nailed, the machine adjusting itself to any slight inequality in the thickness of the timber. The nails are always driven slightly below the surface of the timber, and it is impossible for them to enter the wood crookedly. By the addition of a cleating table, cleats or

battens can be nailed to the box ends, which is a valuable addition where boxes with battened ends are required, as the nails can be driven in either in a straight line, or zig-zag fashion, and clenched securely at the back, in one motion. The machine will nail from 400 to 500 large boxes per day of ten hours, and from 10 gross to 12 gross of small boxes in the same time. With the automatic nail-feed one man only is required to tend the machine, and the power needed to drive them is quite insignificant.

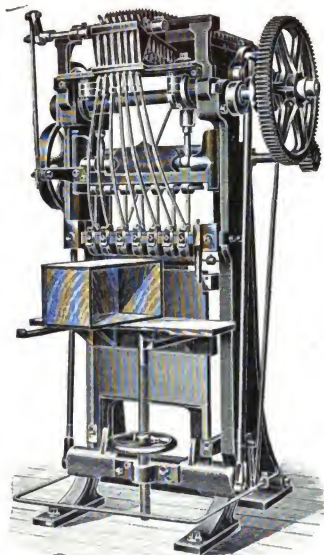


FIG. 236.—BOX-NAILING MACHINE.
(With Automatic Nail Feed.)

When the boxes are branded or printed this is generally effected on the boards before they are put together. Branding is done in a special machine, by the aid of solid brand plates, or by means of loose letters and figures, so that an ordinary lettering may be set up and worked from in a few minutes. The brands are heated either by gas, or by a coke fire; a boy being quite capable of working the machine. Printing is done in a box-board printing machine, such as is shown by Fig. 237, which will readily print 2,000 boards per hour. The type roller shown in the illustration may be adjusted to

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print in any suitable position, on boards of different lengths, the boards being placed in a pile upon the table of the machine, and are automatically fed, one by one, through the rollers to receive the impression. The machine adjusts itself to print upon boards of slightly varying thicknesses, and the strength of the machine enables the operator to stamp the impression into the wood as deeply as in the case of an ordinary brand. The speed of the driving pulley is about 120 revolutions per minute, the power consumed being about one-half H.P.

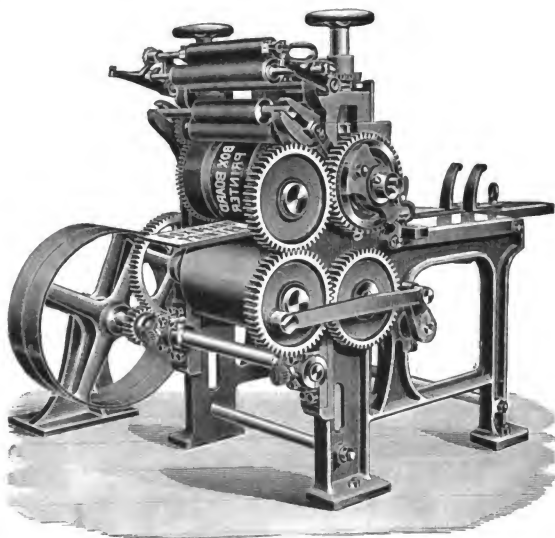


FIG. 237.—BOX-BOARD PRINTING MACHINE.

In the foregoing account of making boxes and packing cases by means of automatic machinery, the list of appliances has by no means been exhausted, but enough has been said to show the importance of such installations, and their bearing upon the financial results of manufacture and distribution.

CHAPTER VIII.

ORGANISATION AND BUILDING.

This, the last chapter of the book, is not the least difficult to put into shape, and for the reason alone that no one particular industry is aimed at. It cannot be a chapter to teach the student how an alkali works should be built, for who knows how long the ordinary alkali work, as we now know it, will be existent, or what changes will come over that industry by reason of the dovetailing in of other processes? Then again, no useful purpose would be served by singling out one industry and laying bare the plan of it. Throughout the whole of these chapters it has been the author's aim to select his processes as examples to explain principle, and this rule must pervade the final chapter.

Chemical works of all descriptions are now carried on in such a manner that only those scientifically organised can be considered permanent. Profits on ordinary articles uncontrolled by syndicates are nearly always of meagre dimensions, and invention so ready and competition so keen that directly any good profit-making concern is launched, it at once finds a host of imitators. This state of things may be to the benefit of the consuming public, but it will have far-reaching consequences in other directions. It will mean in the future that no industry either on the pattern of the older ones, or in any new direction, will dare to start without a very considerable capital reserve, as otherwise it will stand a very good chance of losing all. Further, the days of small works are numbered, at least small chemical establishments making similar articles to those of their larger confrères, as competition and the increased necessity of scientific superintendence will yield the proprietor but a foreman's wage. Of course there are exceptions to every rule, and there are cases in which the geographical position of the works and the personal influence of the proprietor will come in, but taking it as a general rule the office expenses, the cost of selling, the railway carriage, and the cost of scientific supervision, with rent, rates and taxes, and the cost of lighting the works will be a very heavy charge upon the revenue of a small establishment. In all estimates of these charges the author has ever seen, they have been put at too low a figure. Inventors when they devise new processes generally neglect them altogether, and not a few imagine they can beat their fellow men in moderating their requirements, but it generally turns out that proceeding upon too economical a basis they have created a new set of conditions for which they have to pay dearly later on.

With these opening remarks, it may be taken as axioms that a works should never be started unless a very considerable proportion of the capital can be held as a reserve, and the more perishable portions of the plant furnished in duplicate. A works making a product that is also being made by others, being established on a moderate scale, and finding that it can only pay an exceedingly small dividend upon its capital, except by largely increasing its producing capacity, is already on the horns of a dilemma, especially if the world's requirements are already being supplied, as increasing the production under such circumstances must inevitably mean the reduction of values all round. This has had such serious consequences in the past to existing works that there is but little wonder that rings and combinations have sprung up to protect the interests of those affected. These remarks may be considered superfluous in a treatise on Chemical Engineering, but it is only right they should be duly considered by everyone who may have a fancy for manufacturing chemicals on the large scale. It should also be borne in mind that a chemical business to be profitable should be able to redeem the investment within a comparatively short period. In other words, a redemption charge should be added to the cost of manufacture, the difference between this total cost and the net revenue being only devoted to the payment of dividends. The length of this redemption period must naturally depend upon the nature of the business, but ten years will in most cases be a reasonable period. This does not mean that the plant will be worn out in the ten years contemplated, as repairs and renewals will probably have been made out of revenue, but in these days of progress and change an intelligent directorate must always be prepared for the possibility of having to discard and dismantle a comparatively new plant in order to make way for something better. Having now said so much, it is necessary to pass to the first operation of building a chemical works, and that is :—

Selecting a Site. This must to some extent depend upon the products to be manufactured, in which markets they are to be sold, and from whence the raw materials have to be drawn, so that no specific rule can be laid down, except that in a great measure the *locus in quo* must be settled by considerations of carriage. This being granted, there are several matters of vital importance to every works which must not be slurred over—the water supply and drainage, and the deposit for ashes and other solid waste. In the first problem, that of water supply and drainage, it must not be taken for granted that because the site happens to be upon the banks of a stream that the water from that stream can be used freely without let or hindrance, and in these days the matter of the pollution of our rivers has caused more than one works to cease operations. Let no one think he can turn even waste water from steam boilers and steam engines into water-courses without causing pollution. The exhaust from steam engines nearly always contains a considerable proportion of oil or grease ; this floats upon the surface of the condensed water and forms a very unsightly looking effluent, which when turned into an ordinary brook or water-course will sooner or later pollute it with floating masses of oily matter. The

blow-off from steam boilers, also, usually contains large quantities of insoluble matters (see Vol. I., p. 281), especially when alkalis have been employed as disincrusting agents within the boilers. Such liquids should not be allowed to flow into streams without a preliminary purification. Even the soluble matters from a boiler blow-off may become sources of pollution. Sulphate of lime and alkaline sulphates in the presence of soluble lime salts are common and very annoying sources of pollution.

Another source of pollution, the evil effects of which are perhaps not yet sufficiently recognised, is the practice of turning hot waste condensing water and other heated liquids into public water-courses and sewers. It will at once be recognised that a public sewer is scarcely the place in which to turn large quantities of water at temperatures approximating to the boiling point, and even open streams or canals may suffer from such a practice. To heat up the water of a stream, which another manufacturer lower down may be using as a cooling or condensing agent, is to prejudice his interests, so that it would be far better in every case to arrange for cooling waste water to its previous natural temperature when designing the works in the first instance than to be compelled to do so later under legal compulsion. Legal processes are costly luxuries, and the operation of altering one's system cannot always be effected economically after the works have once been laid out.

The practice of turning hot liquids into public streams is very common in most manufacturing districts. In the author's book on "The River Irwell and its Tributaries,"* it is pointed out on pp. 15 and 38 that the temperature of the River Medlock flowing through Manchester was 90° F. (32° C.) at the time the samples were taken, and the temperature of the Tottington Brook flowing through Bury was actually 95° F. (35° C.) owing to the introduction of hot liquids from various industrial establishments. The Bradford Beck, running through Bradford, in Yorkshire, is another instance of pollution by temperature. During the summer months the water flowing in the Beck is usually at a temperature above 100° F. (48° C.), so as to be absolutely useless for cooling purposes.

It may be as well at this point to call attention to the difference between heat and temperature. In the ordinary condensation of steam from steam engines, the temperature of the condensing water before use simply defines the quantity necessary to effect the condensation, and fixes the amount of vacuum that can be attained. The condensation can be effected at any temperature materially below the point of boiling water, but whether or not the operation can be conducted economically depends upon a variety of circumstances.

Reduction of temperature by cooling can, however, only be conducted between very narrow limits, as it will be at once recognised that under ordinary conditions it is not feasible to cool a hot liquid below the initial temperature of the cooling water. In fact, in practice, it is very difficult indeed to cool, even to within several degrees of the initial temperature of the cooling water, as there must be a certain temperature difference to

* Manchester : John Heywood.

allow of the escape of heat from the hot medium to the cooler medium, even when the surfaces have been made very extensive.

In the "good old days," condensing engines were generally provided with ponds or condensation reservoirs, into which the water from the hot well of the air pump was delivered. When the engine worked continuously during the 24 hours, the surface provided for cooling the hot water from 125° F. (52° C.) to 80° F. (27° C.) averaged about 24 square feet per pound of coal burned under the steam boilers per hour; but the appreciation of land values and the larger power installations of later years requiring such extensive areas for cooling purposes paved the way for the universal introduction of non-condensing engines. Condensation reservoirs, so long as they lasted, gave us some reliable figures of the surfaces required for cooling water by exposure to the air. One hundred pounds of steam condensed per hour to produce water of a temperature of 125° F. (52° C.) required 340 square feet of surface in a condensation reservoir to reduce the temperature to 80° F. or 27° C.

Reference has already been made on page 131 of Vol. I. to the process of cooling hot water on the large scale by means of what are known as "cooling towers," now very largely employed for lowering the temperature of water for industrial use. These cooling towers are of three special types: (1) Natural draught, open type, in which the current of air employed in cooling is directed into the apparatus by the direction and force of the wind, the air, saturated or nearly saturated with moisture, escaping at a low level, not more than about 12 feet or 15 feet above the level of the ground. (2) The chimney type, wherein the nearly saturated air is expelled at a high level (60 to 70 feet above the ground), the cold air being induced to enter at the base of the apparatus by the ascensional force of the escaping saturated air in the chimney; and (3) the fan type of cooling tower in which the air required for cooling is forced into the base of the tower by means of a propeller or fan. All forms of cooling towers can be classified under one or other of the foregoing types, to each of which a little attention may now be devoted.

The first, or natural draught, open-air type of cooler, will of course recommend itself on account of its simplicity and lower cost, but there are situations where it could not be employed with advantage, especially in places where the structure would be sheltered by taller buildings, or where the nearly saturated atmosphere leaving the cooler would be detrimental to operations carried on in the immediate neighbourhood. There must always be plenty of open space around a cooler of this type, and when this can be arranged for, the performance is satisfactory. The ground space occupied by this form of cooler is the greatest under the three systems, an apparatus to cool 100,000 gallons of water per hour from 50° C. to 25° C. occupying an area of 2,500 square feet, or a rectangle of 100 ft. × 25 ft. Once fixed in a suitable position, a cooler of this type will work for years without any more attention than it is necessary to give to the water pumps and to keep the spraying channels clean.

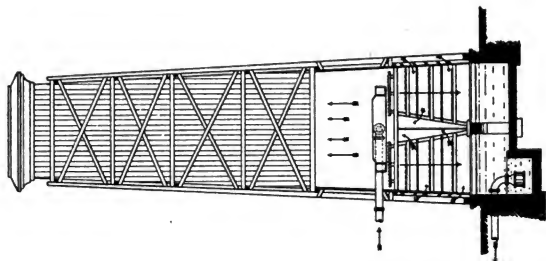


FIG. 239.

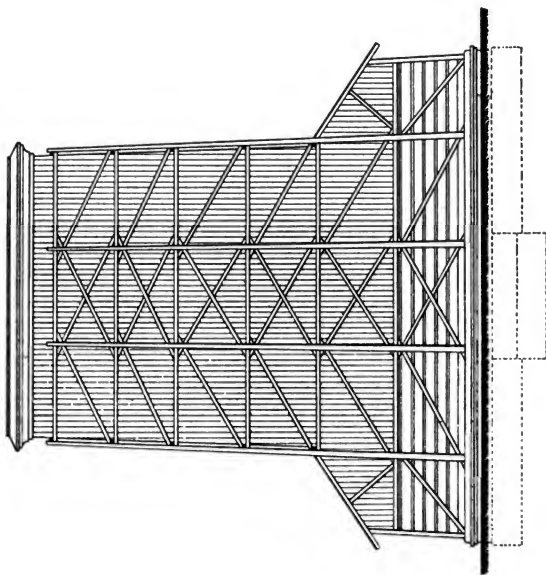


FIG. 238.—CHIMNEY TYPE OF COOLING TOWER.

The ground space occupied by a chimney cooler of similar capacity to the foregoing, cooling through a similar number of degrees, would be 1,500 square feet, or a rectangle of 60 ft. by 25 ft., the top of the chimney being about 65 feet above the ground level. The details and general appearance of a cooler of this type may be seen on reference to Figs. 238 and 239, which is introduced at this point in order to be able to explain the principles upon which it is designed.

A cooling tower of the fan type, of a working capacity of 100,000 gallons of hot water per hour, as in the two former instances, will occupy an area of 500 square feet, or a rectangle measuring 25 ft. by 20 ft., and the forced draught will require for its production two fans, each eight feet in diameter, the pair consuming 25 B.H.P. to drive them at the necessary speed.

The dimensions already given only refer to the cooling of water from 50° C. to 25° C., which, more often than not, is as much as is necessary; but if the cooling has to be carried to the temperature of the air, or a few degrees below it, much more extensive surfaces must be provided. To cool 10,000 gallons of hot water per hour from 50° C. to 15° C. would require 1,000 square feet of ground space for a natural draught cooler of the open type, and the height of the apparatus would need to be double that of the ordinary pattern, in which a less effective cooling is required.

The principle upon which this method of cooling is performed, is to economically bring the greatest volume of air into intimate contact with water, either in the finest possible state of division (*i.e.*, in the form of a spray) or with the most extended moistened surfaces. The cold air abstracts heat from the water, becoming itself heated in consequence, and the water is further cooled by the evaporation of a portion of it. The consumption of air will be least when it enters the apparatus very cold and leaves it very warm, a point to be considered in the fan type, where the cost of moving the air must be considered (see Vol. I., p. 453). When the air supply is unlimited, the wetted surfaces necessary for effective cooling fall to a minimum, and as the air supply is the important factor in the problem, it is necessary to be able to fix this quantity with a fair degree of accuracy in designing cooling plants of definite capacity. In the open type of cooler with natural draught, an air velocity of 5 feet per second is generally assumed, but with the chimney type of cooler (Fig. 239) an air velocity of 10 feet per second will be a safe figure to reckon upon. With the fan type of cooler the air supply is absolutely under control; the velocity may be measured with the anemometer (Vol. I., p. 223) in the chimney, and the speed over the moistened surfaces calculated.

Knowing the principles involved in this method of cooling, it will be found easy to design a tower for any given quantity of hot water, when the temperatures are known, and it would be excellent practice for the student to follow the calculations necessary for determining the details of a tower for cooling 100,000 gallons of water per hour from 50° C. to 25° C., with an air temperature of 10° C. One hundred thousand gallons of water per hour represents one million pounds, and as this weight requires to be cooled through 25° C., the Centigrade heat units (C.H.U.) to be removed amount

to 25,000,000. If we allow so much air at 10°C. to enter the cooler that it leaves at 25°C. , the equations enabling the calculation of all particulars are easily stated, but it is necessary to proceed by steps in order to enable the operations to be understood.

In the first place it is necessary to find out how much cooling will be effected at the various temperatures by one pound of dry air. The air entering the tower at 10°C. and leaving at 25°C. , has consequently been heated through 15°C. by contact with the hot water; one pound of air will therefore have carried away

$$s(t_1 - t) \text{ centigrade heat units,}$$

where s is the specific heat of air, t_1 the temperature of the air leaving the tower, while t is the temperature entering. In the instance before us, the number is 3.56 , or in other words, one pound of dry air will absorb, in being heated from 10°C. to 25°C. , 3.56 C.H.U. Now, as this air has been heated in contact with water, it will have taken up an additional quantity of moisture, the amount of which may readily be calculated from what has been already said on pages 256 and 257. During the process of turning this amount of water into vapour a certain number of heat units have disappeared, and this is a quantity that may readily be calculated. On reference to pp. 256 and 257, it will be found that air at 10°C. , when saturated with moisture contains per cubic foot 0.0768 lb. of dry air and 0.00058 lb. water vapour, so that one pound of dry air is associated with 0.0075 lb. of water. At a temperature of 25°C. , at which the air leaves the cooler, air saturated with moisture contains per cubic foot, 0.0767 lb. of dry air and 0.001526 lb. of water vapour, which is equal to 0.02 lb. of water to each pound of air. But though it may be convenient to reckon upon the air at the lower temperature (10°C.) being saturated with moisture, it would not be safe to reckon upon the air leaving the apparatus in a saturated condition, as it would probably only be eight-tenths saturated, or contain 0.016 pound of water for each pound of air, so that the increment of water per pound of air would be $0.016 - 0.0075 = 0.0085$ lb.

We are now in a position to calculate the heat abstracting value of one pound of air under the given conditions, and from this, the pounds of air necessary to cool the volume of 100,000 gallons per hour of hot water. The mean temperature of the water is 37.5°C. , and taking the latent heat of vapourization as 637 units (Table 83, p. 247), the heat units dissipated by the evaporation of 0.0085 lb. of water will be

$$0.0085 (637 - 37.5) = 5.09 \text{ C.H.U.}$$

One pound of air at 10°C. will therefore carry away 3.56 units by being heated to 25°C. , and the water will consequently lose by this amount, while the evaporation simultaneously accomplished will abstract 5.09 C.H. units more. The total cooling effect of one pound of air is therefore

$$3.56 + 5.09 = 8.65 \text{ C.H. units.}$$

Upon referring once more to the conditions of our problem, it will be found that 25 millions of heat units require to be abstracted per hour, so that

this number divided by 8.65 will give the number of pounds of air necessary. It will be near enough for the purposes of this illustration to call the quantity three million pounds.

We now come to the most important point in the design of cooling towers, viz., the extent of the moistened surfaces over which it is necessary to pass the calculated quantity of air. In the present instance, this quantity is three million pounds, or 40 million cubic feet per hour. In order to arrive at the surface required, the heat units abstracted by evaporation must be neglected, considering only the heat imparted to the air in passing through the tower. This amounts to

$$3,000,000 \times 3.56 = 10,680,000 \text{ C.H.U.}$$

It has been found by experiment that water of the foregoing temperatures will lose about 120 C.H. units per square foot when exposed to still air, so that 10,680,000 divided by 120 gives us 89,000 square feet as the necessary area over which the water is to flow when the velocity of the air current is at a minimum. The number 120 may be analysed so as to adapt it to higher velocities and to variations in mean temperature difference. In this way it becomes $K \cdot t_m$, K being a coefficient dependent upon the velocity of the air, and t_m being the mean temperature difference between the water and the air. In this instance t_m by Grashof's formula (p. 125) is 19.65° , say 20°C. , and K is 6.0. To adapt K when the velocity of the air (v) is variable it must be considered as

$$K = 2 + 4\sqrt{v}$$

v being unity in still air and rising to a high figure in a brisk wind or when the current is artificially accelerated. With chimney coolers of the pattern shown by Fig. 239, the draught is usually 10 feet per second, while in the fan type of cooler the velocity sometimes approaches 50 feet per second.

In the case we have been considering, the cooler was of the open type with natural draught in still air; we may therefore consider its dimensions if desired to be of the chimney type and of similar capacity to the foregoing. We have still to part with 10,680,000 units of heat, the mean temperature difference is the same, but the coefficient K will have been increased by reason of the velocity of the air in the chimney. In fact, we may now give a velocity to v of 9 ft. per second. It will be seen from the illustration (Fig. 238) that the chimney proper of the cooler occupies about two-thirds the area of the ground space covered, and it has been already pointed out that a cooler of this capacity is furnished with a chimney 64 feet in height. Now by reference to formula e on page 48, it will be found the *theoretical* velocity for the air in such a chimney is 14 ft. per second, but practically 9 ft. per second would be a safer figure to take. At 9 ft. per second, the value of K becomes

$$K = 2 + 4\sqrt{9} = 14; \text{ and}$$

this multiplied by the mean temperature difference 20, gives 280, which, divided into our 10,680,000 units, gives 38,000 square feet as the area of the moistened surfaces necessary to dissipate the heat from the 100,000 gallons of hot water per hour. The influence of the velocity of the air is

now apparent, and as 40 millions of cubic feet of air per hour are necessary for the cooling, it remains to be seen whether this volume may reasonably be expected to pass through the tower. If we take the area of the chimney as being 1,000 square feet, a velocity of 14 feet per second will give over 50 million cubic feet of air per hour, which is more than required, but as we have arbitrarily reduced the theoretical velocity to 9 feet per second, this calculation yields nearly $32\frac{1}{2}$ million cubic feet per hour, or less than is required, but, on the other hand, it must be admitted that in a chimney of this kind the actual velocity would most probably be higher than 9 ft. per second.

It may be remarked here that this matter has been treated at such a length in this place, in order to set before the reader the value and mode of using information and tables that have been given in the previous chapters. At first sight, perhaps, the operation of drying wood-pulp and cooling water would seem to have but little connection, but, as will be seen, the study of the one leads up to the elucidation of the other. So it is also with most other problems with which the Chemical Engineer has to deal; in fact, there will be found but very few problems indeed that cannot be solved through some explanation or rule to be found in these pages.

As to the deposition of solid refuse, two points must be carefully investigated, quality and space. Will the refuse when exposed to the weather yield anything soluble to rain water? If so, where will that soluble matter find its way? These questions—important questions too—cannot be shelved with impunity, as sooner or later they will be asked, and will have to be answered correctly.

If the solid waste of the establishment consists only of the ashes from the steam boilers, there is still danger of stream pollution, as such heaps will usually give a sulphate of iron drainage, which is always unsightly, to say the least of it. The bulk, too, must be considered. One hundred tons of slack burned per week will produce about 15 or 20 tons of ash and clinker, which will measure at least 10 cubic yards, and for which a "tip" must be found close at hand. Here the configuration of the ground will come in. On the whole, level ground is the best for building on, but if low lying ground is capable of first acting as a "tip," and afterwards of being built upon, such a point is worth consideration. It is not often, however, that a chemical works is content with making ash and clinker. There are many other forms of solid refuse that must be carefully and regularly removed, and it is not always that sufficient space is arranged for at the outset, so that after a few years the owner of a works is often called upon to pay an exorbitant price for his "tip," out of all proportion to its real value and usefulness.

Another point to carefully consider in the selection of a site is the proximity to land under cultivation. A works may do no damage to crops growing close to the walls of the establishment, but the farmer will not think so, and as soon as the works are in operation, and sometimes even before it, the farmer will fancy he spies damage, especially if he thinks the owner of the

works has the complacency to be bled without murmuring. When a site has been actually acquired, the author recommends the proprietor to have the vicinity well photographed, and the prints signed, witnessed and dated, and kept for reference.

Laying out the Works. — Let us now suppose a square site to have been selected with a main road running past one side of the square, two different lines of railway running by two other sides, and a canal running by the fourth side, with low-lying ground on at least half the ground sufficient for a tip to last forty years. This may be considered Utopian, but the author has seen it more than once in the course of his travels. The main road should be built to, so that callers may not have to pass through the works on their way to the offices when on business, and that through the time office gateway may be the shortest way home for the men leaving work. It is imperative that there be only one way in and out for the workmen, as there can be no discipline unless this is so, or at least its equivalent. There should also be a goods entrance from the main road, with a lorry weighbridge ready for use at any time. No matter how well the works are laid out for railway traffic, sooner or later goods will be brought in by road, and it is unfortunate that there is a certain class of tradesmen who soon discover whether or not their delivery cart has to pass over a weighbridge. This leads, of course, to the offices being located by the roadside, but to this reference will be made later on.

The usefulness of the canal which bounds the fourth side of the property will necessarily depend upon the position of the plot. If it is the main waterway to a port of shipment it should be developed, and a wharf made in such a manner that a travelling crane may run from end to end, and so discharge the contents of boats into ordinary trucks made to run on to the lines of the works railway system.

It is presumed that the two lines of railway running on each side of the site are owned by competing systems, and these, with the canal and roadway, will to a great measure serve as a check upon exorbitant railway rates. There is no other method of exhortation that is of any use when dealing with a railway company. These two lines of rail should be made to run into the works system, and as much of the sidings as possible should be in the hands of the owner of the works. It is a great mistake to allow the railway people to be complete masters of the sidings, as everyone who has allowed it to be so has found to his sorrow.

The railway system, and, in fact, all systems of carriage, are connected with three main operations:—(1) The bringing in and depositing of raw materials and fuel; (2) with handling intermediate products; and (3) the dispatch of finished articles, and it must not be forgotten that these operations are practically continuous. The manager must, therefore, ask himself the question—How are the works going to be supplied when the loco. (if only one be used) is in the repair shop?—a situation in which it will most undoubtedly find itself on many occasions.

In bringing in raw materials and fuel, it is the custom in many works to cast out or unload the trucks by the railway side and to trim to a heap

on either side of the rails, and the stock is kept in this way. In a good many cases this plan answers well enough, but it is doubtful whether it is superior to that of elevating the material at once into store bins, from which it is constantly withdrawn for use. Elevating and conveying machinery comes in well here, and this has been already touched upon in Chapter VII., Vol. I. Elevating and conveying appliances must be mainly depended upon for handling the intermediate products of the establishment, moving the substances from furnaces to vats, mills or other places, as, when dealing with large quantities of materials, hand labour is now no longer economical. At the Barberton works of the Columbia Chemical Company, in Ohio, U.S.A., all these things have been arranged with a completeness that leaves nothing to be desired, and materials are not handled once too often. If the work is large enough and local circumstances will allow of it, an overhead railway line, combined with another on the ground level, may be found the most advantageous arrangement. This is the disposition at Barberton.

In the dispatch of finished articles, whether by rail or road, the levels should be so arranged that drums or casks may be rolled on one continuous level, neither up step nor down step, from the store-shed floor or packing floor, to the lorry-stage or the floor of the railway truck. The loading and unloading of material in bulk is also a matter that requires some careful consideration. In loading up such material as salt-cake, one often sees the wheelbarrow and plank employed far more often than there is need for, as if the existence of better appliances was not known. The endless conveyor would be found a useful adjunct here—not for the purpose of loading direct into the railway wagon, but to convey it into an overhead hopper or “bin,” from which several wagons may be loaded expeditiously and in rapid sequence.

In loading canal boats, no matter of what size they may be, it is only material in bulk that can be loaded from a hopper; the boat is always some feet below the landing stage, so that arrangements must be made for hoisting up or for lowering goods in casks, barrels, drums or bags. Casks are lowered by chain grips, which clutch each cask by both heads, the endless chain carrying the grips being hung by the hook on the crane. Strong drums are also loaded in the same way, but weak drums or bags are raised and lowered in “slings,” which consist of endless pieces of stout rope, so used as to form a loop, which grips the loaded bag, which then can be either raised or lowered by means of the crane. Where the electric current is at hand, the cheapness and simplicity of the electric crane should not be overlooked.

It often happens that the ordinary railway, or even tram lines, cannot conveniently be employed for the conveyance of materials. In such cases aerial ropeways have much to commend them, as they can be worked for about threepence per ton per mile, which includes labour and repairs, taxes, and way-leaves where the ropeway passes over adjacent ground. The illustration shown by Fig. 240 is a stage in the line of the Solvay Process Company, near Syracuse, N.Y., which is used for the transportation of limestone rock from the quarry, over three miles away from the works. It was put up in 1891 by the Trenton Iron Co., of Trenton, N.J., for a daily

capacity of 750 tons. The line has proved so satisfactory that the Solvay Co. have built an extension and branch lines, the total length of which is about equal to the original line. The elevated station at the works has been entirely re-modelled, and now not only constitutes the terminus bringing down rock from the quarries, but is also the terminus of a couple of branch lines for handling coke, ashes and refuse material, thus making it a central point from which all these materials are brought in and sent out to their various destinations. In collecting and distributing the materials about the works, transfer cars are extensively used, and the tramway cars are raised and lowered at the central station by elevators specially designed for the purpose. A line of this capacity could be installed to-day, erected, and ready to run, for about £10,000., and it would require about 25 I.H.P. to operate it. The cars running on the aerial ropes may be seen in Fig. 241.



FIG 240.—AERIAL ROPEWAY NEAR SYRACUSE, N.Y.
(By the Trenton Iron Co, N.J., U.S.A.)

Leaving now the question of receiving and distributing the traffic of goods in and out by rail or ropeway, some attention must be paid to the ordinary cart roads and footpaths, these being arranged as the necessities of the case and the disposition of the plant may determine. Where the position of the cart road is likely to be shifting, too much money cannot be afforded for foundations, but if the roadway is to be permanent, then the bottom must be pitched with good rock of some suitable kind. Slag, generally copper furnace slag in the north, is employed for "bottoming" roads and railways, but iron-works slag, if employed, should be well selected, as some varieties holding free lime in excess, are apt to go to pieces in wet situations, or even after a series of heavy rain showers.

When all the foregoing details have been settled, it is time to weave in with them the location of the various portions of plant and the buildings containing them. Naturally one must wait upon the other, and until the

whole disposition is settled, every detail is liable to change of place. The author knows no better plan of "laying out" than to place the dimensions of the site upon a large drawing board, to scale, and to cut out each separate part of the apparatus to the same scale from stout Bristol board, for arranging upon the plan of the site. These separate pieces, cut out of the Bristol board with a sharp knife, can be arranged on the drawing board as experience may direct, and all the conditions taken into account, as a "bird's-eye view" of the complete establishment can thus be made. It is not often that the first cast of the plant will be successful; days, weeks, and even months have been spent in getting at the best arrangement, as every problem of this character is a separate one, and bristles with difficulties inherent in itself, and which are of too changing a nature to be dealt with under any general rule.

Amidst all the necessary conditions for the proper conduct of the works afterwards, there will have to be taken into account the flues, the chimneys, the drains, both for rain water and for polluted water, the ways for steam mains, mains for compressed air, water and gas, and the conductors for electric current, if that be included in the installation. All these details must be plainly seen upon the drawing board as movable pieces, ere one could hope even to commence the block plan. The drains will, of course, be below the natural surface of the ground, and below all incoming sources of water, and means must be provided during building] for periodically cleaning them out afterwards, without danger to the workmen. Many workmen have lost their lives owing to neglect of this precaution. The drains should always be well below the flues, and this proviso may in many cases be brought about by building the flues upon the ground level, and gradually filling up over them with the ashes and clinkers and "spoil" from necessary excavations during construction, instead of digging out, which is always a considerable item of cost. In this way the permanent yard-level of the works will be some six or seven feet above the natural level. This must be allowed for in dealing with contiguous levels, but it ensures a free tip for solid refuse for some years, and a free drainage for rain.

The method of building the flues directly upon the surface could not be always followed on account of the nature of the ground, but it is seldom that such a plan could not be followed, as heavy portions of the plant requiring good foundations may still have each its own special foundation going down to a solid bed, or what is almost as good in many cases, a bed of concrete about two feet in thickness, extending over the whole area of support. Flues should be built large enough, but the author would again call attention to the remarks made on page 80 as to the multiplication of chimneys of smaller height, instead of building excessively high shafts.

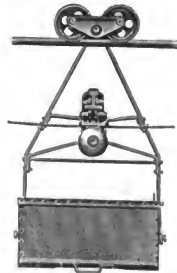


FIG. 241 —
AERIAL ROPEWAY CAR.
(By the Trenton Iron Co.)

In most cases, black smoke need not occur, and there is a great difficulty in locating the furnace which is at fault when all the flues pass into one tall chimney.

In every disposition of plant, considerable attention should be paid to the water supply. Probably the best method is to build a water tower with tank upon the top, at a higher level than that of any place where it is likely to be used, so that subsidiary pumping can be dispensed with as much as possible. This tank, into which the water pumps deliver, may be placed upon a framework of iron girders, and have an overflow delivering into a second tank of larger capacity placed immediately under, which might be called the low pressure tank. A great deal of the water would not be

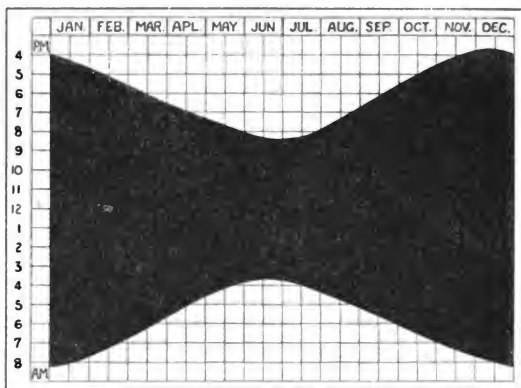


FIG. 242.—SHOWING THE HOURS OF ARTIFICIAL LIGHTING.

required at the high pressure, but it is there ready for connecting up when required, without disturbing existing arrangements, and is especially useful for connecting up with the fire main. Of course, a simpler method would be to increase the pressure on the delivery main by the addition of a weighted escape valve on the outlet, using the water tank only for low pressure service, connecting up with the delivery pipe direct when high pressure water is needed. The author has seen this done on several occasions, but it has many objections.

Well drilling may be mentioned at this point, in order to indicate its cost, as it sometimes has to be entered upon. The cost of a diamond drill to bore 1,200 feet, will be somewhere about £1,100., and the cost of working it about £1 per foot of depth on the average. For depths of 200 to 400 feet, the cost should not be more than 14s. per foot in very hard ground.

The lighting of the works cannot be entered upon in detail. If the operations are carried on during the whole 24 hours, the lighting will be required for 5,000 hours during the year, and provision must be made for the maximum daily requirements, which will be from Dec. 1st to Feb. 1st, when lighting will be required from 4 o'clock in the evening until 8 o'clock in the morning if the weather is good, which is 16 hours out of the 24, and more than this will be required if the weather is dull. The hours during which it is necessary to light up at various times of the year may be seen at a glance by consulting Fig. 242. The black portion represents the hours of darkness.

Foundations and Buildings.—Very little information of a definite nature can be given under this heading, as in most chemical industries the arrangement and requirements are special. There are a few things, however, that have to be studied from a common basis, chiefly the pressure on foundations and the weight that may safely be placed upon floors. Under the first head, the bearing power of soils varies considerably. A good firm rock may sustain from 18 tons to 150 tons per square foot, while a compact gravel, or coarse sand not liable to be carried away by water, or into crevices by dryness, will sustain from 8 tons to 12 tons per square foot. The crushing stress of various British stones may be found in Vol. I., p. 100, while in Table 5, p. 99, of the same volume, Prof. Bauschinger's experiments upon Bavarian stones are given in detail. A stiff dry clay will safely support from 4 tons to 6 tons per square foot, but a soft clay should not be burdened with more than one ton per square foot. Rubble stone set with cement mortar will sustain 6 tons; concrete, 4 tons; bricks, with lime mortar, 3 tons; common bricks with cement mortar, 5 tons; blue bricks and cement mortar, 12 tons.

The strength of the girders and floor joists in any building will naturally be made dependent upon the weight the floor is required to carry, and a very wide latitude should be given in all such cases. In manufacturing chemistry one never does know for long together how much weight it is necessary to squeeze into any particular spot, and in many instances known to the author, the best disposition of plant has had to be abandoned on account of the main girders being too weak to allow it. A crowd of people, packed as close as may be on to the floor of a building, means a distributed load of 84 lbs. per square foot. A light warehouse floor should be capable of sustaining 200 lbs. per square foot, heavy warehouse floors, 250 lbs., while shop floors destined to receive heavy machinery should be capable of sustaining from 300 lbs. to 500 lbs. per square foot. When store-rooms are being designed, to contain solid weights of materials, great care should be taken to rather over-estimate than otherwise, the largest stock they will ever be pressed to contain, and especially so when the material is packed in bags.

The roofs and sheds necessary to cover the plant and apparatus and for use as store sheds, as well as those required for workshops, are of so various a description and subject to so much personal design, that the matter of cost alone concerns us here. The wooden lattice-girder roof covered with felt (see Vol. I., p. 92) is very largely employed in the chemical

industries, but without it its life is short, and it thereby becomes an expensive item. A large roof, say up to 80 feet clear space, can be built and finished complete for about 4s. 6d. per square yard, and smaller roofs for somewhat less than 6s. per square yard. They require tarring at least once during the season, and this expense is a continuous one during the whole of their life. They are quite suitable for stores, but not appropriate for use in manufacturing operations where the frail timber-work will be exposed either to acid fumes or alkaline vapours, or to the continued action of steam, which softens the lattice and causes collapse.

A slated shed roof of 300 square yards more or less, may be stated to cost 21s. per square yard of ground space covered, while if there be an intermediate floor, it is very probable that the cost per square yard covered will rise to 45s. A shed designed by the author 30 yards square, in three bays, each 30 feet span, the roof supported on cast iron columns standing 20 feet above the ground, lighted from above with 210 squares of rough plate glass, each 48 ins. \times 12 ins., and provision made for an intermediate floor, when required, cost in 1897 slightly over £1,300. The cast-iron columns were set upon concrete blocks, each three feet in the cube, and the sides boarded in with inch boarding.

In some works large "wells" or underground tanks are required. Thus, in a tar works it is often necessary to store the tar that comes in for distillation, so as to equalise the work on the distilling plant. Again, in sulphate of ammonia works, a large gas-liquor storage is often provided. These large tanks are often built of brick, and puddled behind with well-tempered clay and covered with a circular lattice girder and felt roof, but they are nearly as often made of cement concrete, which is quite as efficient and cheaper. A circular tank 60 feet in diameter and 20 feet deep, will hold at least 1,500 tons of water, and if well built in brick and puddle will cost £700, or 7s. per cubic yard of capacity. If such a tank be built in concrete, without puddle, it would cost 5s. per cubic yard of capacity. Such tanks are used for "creosote wells" in tar distilling works.

The Offices and Laboratory.—It may be considered by those who have not given much thought to the matter, that the situation and arrangement of the offices and laboratories is but a small matter, and scarcely worth any extra amount of attention. The author has in fact been told this on several occasions, and no greater fallacy can exist. The offices exist for the main purpose of exercising control over the materials ordered and paid for, and of the wages and other expenses paid out. It keeps a record of them, so that these items may be brought up for periodical review and revision if necessary, and in a well organised establishment it should be possible to ascertain the exact state of the works outside, and of each manufacturing department without having to go into the works themselves. The office is also the head quarters of the "sales department," and these two departments must work "hand and glove" with each other, if any financial benefit is to be obtained. The carrying out of such a system of book-keeping, as is foreshadowed in the foregoing remarks, is a matter of accountancy pure and simple, and a treatise could well be written on

this subject alone, but it will not be dealt with here, as it is a matter that only concerns the Chemical Engineer inasmuch as it compels him to arrange the works and dispose the buildings in such a manner that all details may pass into and from the offices with the least possible trouble.

The present method of manufacturing is to make each superintendent responsible for the materials entrusted to his charge during manufacture, and this means the selection of intelligent men of fair education for such posts. In days happily rapidly passing away this was not the case, and men were often selected for their excellence in bullying the workmen, than for any capacity of understanding technical or financial problems. And what did the old system lead to? Perfect vandalism in the way plant and apparatus were treated—pipes torn down and consigned to the "tip," towers unpacked and repacked without any scientific reason being adduced for its necessity, or without counting the cost—it was about time that the need for a technical training was appreciated. With men of scientific training in accountancy, no less than in actual manufacturing operations, the stock-taking, the averaging of wages, the apportionment of general expenses, repairs, stores, and a host of other daily considerations, would be as easy as A B C if the superintendent has an interest in his work, *and has time for thinking*. Humdrum routine work is not the labour that should be put upon superintendents with heavy responsibilities, but it has been so.

The office, or that portion of it known generally as the time-office, should be so placed that every workman, no matter what his position may be, has to pass by the check board, and it is here that the advantages of good discipline come in. The blacksmith has a "striker," the plumber has a "lad," most other tradesmen have "labourers," and it is not an uncommon thing to find that all their checks are in the appointed box at bell ring in the morning, but that some of the men themselves are only there in spirit until after breakfast time. The offices should be so arranged as to prevent this. In this connection the Bundy Time Recorder may be introduced here, but there are other forms of instrument which will perhaps answer as well. The Bundy Recorder is operated by the workman himself, and works in conjunction with the mechanism of an ordinary timepiece, keeping accurate time. Each workman has a key instead of the usual metal check, numbered in two places with his works number, on the handle and on the face of the bit, the figures on the latter standing out in relief. On entering and leaving the works he takes the key from a board close by, inserts the key in the keyhole of the clock, gives it a quarter turn, takes it out again and hangs it on another board on the opposite side of the clock. Each time the key is inserted and turned, a small gong is sounded to apprise the time-keeper that a workman has passed into or left the works. The turning of the key puts the mechanism of the apparatus into operation, and causes a rubber hammer to strike an inked ribbon against a piece of tape. This tape when struck is impressed with the hour, the minute, and the workman's number, as shown in the illustration Fig. 243. In order that a distinction may be made between the register showing the time of men entering and

leaving the works, a star is printed to the left of the hour on the tape. This change in the stamping is effected by the aid of a lever attached to the apparatus. The tape is taken out once a day, or oftener if required, by the time-keeper or other person in charge of the key of the clock. The makers recommend one of these instruments for each 200 workmen, as being most convenient for a large works, and where more than one is required they can be placed in close proximity to each other, under the observation of the time-keeper. For superintendents and others, it is the practice in some

6	45	56
6	49	325
6	55	98
7	1	87
7	4	124
* 12	1	98
* 12	2	87
* 12	3	124
* 12	4	56
* 12	7	325
12	50	124
12	52	98
12	55	87
12	56	325

FIG. 243.—
TAYLOR BUNDA TIME RECORDER.

works to use a recorder of another pattern, in which a roll of paper travelling under a slotted disc, by clockwork, enables the employé to record his initials on entering or leaving the works. The "Bundy" Time Recorder is made by the International Time Recording Co., 171, Queen Victoria-street, London; the "Dey" Time Register by Messrs. Howard Bros., 38, South Castle-street, Liverpool; while the "Realm" recorders are made by the Llewellyn's Machine Co., King's-square, Bristol. It will at once be seen that any attempt to carry out such a system will result in failure if the workmen are allowed to leave the works by other points of necessity open, such as the railway sidings, etc.

As to the offices themselves, there is not much to consider, except it be the lighting, the warming, the ventilating, the lavatories, and the telephone. The author has had some experience in these matters, and just a few words may be useful. Put in the electric light wherever possible, and it should be possible in every case. Gas is only a good second, but it is necessary for the laboratory—it can be made from ordinary boiler slack, and its cost is about tenpence per thousand cubic feet, when made expressly for this purpose. The warming and ventilation should be duly considered. A good supply of fresh air is necessary, but there must not be draughts, and the incoming air should be warmed and moistened when necessary. There is no trouble about these things if duly considered and arranged for at the commencement, but as cold fresh air generally comes in when the architect expected the vitiated air to go out, the author feels constrained to mention these details.

As to warming, a temperature of 60° F. is necessary for those who have to sit still in it. In summer, of course, it will rise above this, and it should be allowed to do so, cool the air in summer would be a more com-

pletely saturate it with moisture, while heating it in winter will lower the saturation point and make the air uncomfortably dry. Perhaps the most healthy way of heating large offices is by a combination of open fireplaces and hot-water pipes, the latter being of a capacity insufficient to produce the normal temperature during cold weather, when the open fireplaces can be used as an additional source of heat. To trust to hot-water pipes entirely is a mistake. There is sure to come a time when they are out of action, and this in the very nature of things is certain to be on the coldest days. Heating by means of slow combustion stoves is cheap, simple and effective, but such warmth is more often than not drying and oppressive, on account of the excessive dryness of the heated air. It stands to reason, however, that this fault may be automatically corrected, but it is seldom arranged for, or even thought of, in setting up such a stove. A slow combustion stove should always be large enough, so as to be well above its work, in order that the combustion may go on with extreme slowness; and the ventilation exit requires more attention than in the case of open fireplaces.

How often does a stranger visit an ordinary office, and hear the business that is being transacted through the telephone? There is no need to answer the question. There is a necessity for calling attention to the advisability of completely isolating this instrument, as such conditions do not always exist. The telephone room should be so placed and constructed that not a sound can be heard outside of it.

In every well organised establishment, the laboratory, or the main laboratory, where there are several, should be near the offices, if not forming a part of them, and the same may be said of the drawing office. No one should be able to go in or out of these departments, unless under the lynx eye of the "lodge-keeper," and this can only be ensured by considering the matter during the laying out and arranging of the premises.

The General Stores.—In works of all kinds the general stores are matters of great importance, and do not always receive the attention they deserve. In small works stores are often kept in a very loose manner, oils, waste, picks, shovels, buckets, brooms and brushes being simply "given out" on requisition, and there the matter ends. But the stores are worthy of a better treatment than this, representing a large selling establishment in which the buying at advantageous prices is possible on account of the quantity taken at once. But though the buying is effected at a low wholesale rate, it does not follow that the individual processes should be charged with them at the initial rate. There are charges in connection with the stores just as there are on a shop-keeper's ordinary business, the store-keeper's wages, the cost of unloading, tidying up, dealing with empty packages and the like, which must go to swell the original cost of the article. These expenses may be minimised by suitably designing and locating the stores so that unloading from railway trucks or road is effected quickly and without undue labour. Another, and a very important item, is in seeing that the machinery is so perfect that workmen can get necessary articles from the stores without having to wait for them; if it takes a workman ten minutes instead of five minutes to get what he requires, that extra five

minutes is a loss to the establishment as assuredly as if the man had been paid for doing nothing. A manager once told the author that he made it as difficult as he knew how for a workman to get anything from the stores, thinking perhaps that he was effecting an economy, but if he had been a wise man he would have saved the workman's time in attempting to fetch what in his (the manager's) judgment was unnecessary. If any material is needed from the stores the sooner it is given out and applied, the better. One would scarcely have thought it necessary to insist upon such a proposition.

The actual booking of the stores to the various processes in which they are used is again a matter of accountancy, but as the accountant as a rule, has no technical knowledge, he must be guided in this by someone who has. All the Chemical Engineer can do is to provide means to the end, to ensure that the general stores shall not be placed in unsuitable situations, and that all appliances used in connection therewith shall be effective and labour saving. He must also ensure the inspection of all goods that come strictly within his purview before acknowledging their receipt. The stores, which in the main consist (in a chemical works) of "materials for repairs," are often a sore place for leakage, and require quite as much attention as the working of a process. The stock-taking in the stores should be so arranged as to go on concurrently with the receipt and issue of goods. It is an absurd practice to wait until the end of each year or each half-year to find out whether there has been any misfeasance.

The Workshops.—In most chemical establishments the workshops exist primarily for the execution of repairs, which is more often than not a very heavy item. Some manufacturers complain that repairs done at home are not so satisfactory as when done by a tradesman outside the works, and no doubt in many cases this is so, especially when any dark shed is considered good enough to house a mechanic, a joiner, or a smith. That Saturnine fraternity, the plumbers, would not perhaps now be such a maligned race if they had been reared in the purifying sunshine instead of being stowed away under the chambers and in other dark holes. The importance of a good set of workshops is at once evident in a large works, and their location and arrangement is a matter of some moment to the Chemical Engineer. The workshops should not be looked upon as isolated units: the organisation should be such that it allows one competent man to superintend the whole, and under this system there should be no conflict between the various shops. In the author's opinion the various shops should be under one roof, or at least contiguous to each other, as it is very rare to find a job that can be commenced and completed without the help of men from another shop. The shops should be roomy, with plenty of space for storage of material in only occasional use, such as centres for the brick-setter, mandrils for the plumber, and especially for work in progress. Unless this space is provided these things will never be found when required, and will have to be provided anew when they become necessary. Power should be furnished to all the shops without exception, and there is no doubt that this can most conveniently be done by electricity, wherever the current

is available. This could not always be, but as small motors can now be fixed to every kind of machine, lathes, drills, rivetters, saws, and the like, the possibility of adapting it to repair shops is a matter that should not be overlooked in the laying out of the works. In the joiner's shop a circular saw, a band saw, and a mortice and tenon machine are absolutely necessary in most works, while the mechanic's shop finds a lathe, a drilling machine, and a screwing machine to be indispensable articles. The lathe should be capable of turning up valves and valve seats for pumps, and skimming over occasionally the conical plugs of metal cocks, which will effect a great saving in purchases, but a lathe with an exceptionally long bed is not required except for shafting, and shafting can now be purchased at far less cost than it can be turned out by the occasional running of a lathe in a chemical works. There are several other labour-saving machines that may find a place in many works, but the superintendent of the repair department will be the person to judge whether their introduction would lead to efficiency or economy. There is but little advantage to be gained with machinery if only put to very occasional use, and in such cases it would be cheaper to send the work out.

The question of tools and tool stores for the workshops' exclusive use is a matter that deserves more than ordinary consideration. Such a question cannot be settled off-hand, but the ordinary store-keeper is certainly not the person to give out, or look after, such things as files, tool-steel, hammers, though this is done in a great many works; they should be wholesaled to the repairs superintendent, who should retail them to his subordinates. How often is it the case in a works, that a repair was not executed in the night turn, "because the store was locked up," and if a loose system prevails, of allowing anyone to go into the stores, how often has it proved satisfactory in the long run? These are simple matters, and many managers who now fancy their system as good as can be devised, would soon be undeceived if they were to take charge of the stores key for a week.

In this connection the labourers' department may be mentioned. The foreman labourer will need a store shed. He should be responsible for blocks, ropes, barrows, shovels, picks, buckets, brushes, and other things in use by his men, and if he is negligent, there will soon be not a single tool to use. Where they go, in many works, is a mystery, which soon disappears with good organisation and discipline. The care of ropes is a most important matter to the foreman labourer. He is the responsible man for erecting scaffolds, using the block and fall wherever it is required, lifting and lowering heavy weights,—and if he cannot depend upon his ropes, it is a bad look-out for the safety of the workmen who are under his instructions.

In a chemical works, ropes are subject to occasional exceptional damage, from contact with acids and alkalis, and in fact from contact with chemicals of all kinds, so that the greatest care should be taken to preserve them sound and undamaged, and never to use a rope about which there is the faintest shade of suspicion. With a negligent foreman, a new rope will have to be purchased for every fresh job; his barrows will be all in the repair shop at once; his chains will all be rusty; his spades and shovels all worn out,

and his picks will always want sharpening on the advent of any work to do. The cost of repairs in such an establishment will not be found a very satisfactory figure.

Fire-Preventing Appliances.—Whether this term be correct or not depends upon the application of it. In most works there are fire-extinguishing appliances of greater or less efficiency, but in many cases it would be a stretch of the imagination to say they were fire-preventing appliances. A great deal may be done in the way of fire-prevention by a proper arrangement of the plant and apparatus, and the insurance companies might do better by having the report of a chemical expert upon the fire risks of an establishment than by trusting alone to the report of one of their own agents, who more often than not is utterly ignorant of the dangers incident to such establishments. As a rule, chemical works offer no unusual risks, but there are exceptions to this rule, and it is unfair that the safe works should bear the burden of those that are unsafe.

The organisation of the fire-extinguishing department should be complete, and extend to the plant as well as to the personnel. Even in an unsafe works, there are many parts of it where no fire could possibly occur, yet it would not be a wise policy to deny that portion any share in the general scheme. The first requirement is an ample supply of water under good pressure, and if this can be ensured during the first few minutes of the outbreak of a fire, there need be but little anxiety. A tall overhead tank or water tower, such as has been already mentioned, will serve not only for the works supply but for the fire main, up to a certain point; and near all risky processes a hydrant, or series of hydrants, should be fixed, with a hose-pipe hanging by its side upon the wall, or otherwise placed so that it can be put in action immediately. If the water tower is not possible, the rising main from the pump may be turned into a fire-main by a loaded escape valve, as already explained, but this is only a makeshift. A very high pressure is necessary for effective fire-streams. A $1\frac{1}{4}$ inch smooth nozzle, supplied through 100 feet of ordinary $2\frac{1}{2}$ inch rubber lined hose with water at 100 lbs. pressure per square inch at the point of delivery, will deliver 390 gallons per minute through a horizontal distance of 90 feet, or 100 feet vertically. The pressure at the pump will require to be, in such a case, not less than 210 lbs. per square inch.

A very interesting paper on "Fire Service in Factories, Works, etc.," by Mr. Harold Sumner, was published in 1898 by the British Fire Prevention Committee,* to which the reader is referred. As an appendix to this paper an account is given of the Fire-protective arrangements at the works of the Standish Co., Ltd., near Wigan, from which the following account has been taken:—

"The water supply for the works comprises two reservoirs containing 3,000,000 gallons and 400,000 gallons respectively, with daily supply of 750,000 gallons. There are also some brooks, a river, and a minor reservoir.

There is a double acting high speed stationary fire pump, duplex type, with steam cylinders 14 inches in diameter, water cylinders 7 inches, and

* London: 1, Waterloo Place, Pall Mall. Price One Shilling.

8-inch stroke. Capacity, 800 gallons per minute. This fire pump is housed in a separate building in close proximity to a range of boilers, and can take its water supply from either of the two main reservoirs. It feeds two 6-inch cast-iron mains forming a complete circuit round the works. It is fitted with bye-pass, relief valve, and hose couplings, and is kept ready for instant use. The external 6-inch mains feed 26 hydrants, the position of which is denoted by wall plates. Each hydrant is placed in a cement-lined brick chamber which is drained. Each main is controlled by a valve in the fire pump house, sectional cut-off valves being also provided. The piping is so arranged that in case of breakdown of this pump, two boiler feed pumps can be utilised, giving a delivery of about 500 gallons a minute.

Several internal mains are connected with the external mains by means of valves which are controlled outside the buildings. The internal mains are 4-inch cast-iron flanged pipes, and are connected with an overhead tank about 35 feet high, carried on four walls and containing 24,000 gallons of water. This tank is fed from a third and smaller reservoir by a direct-acting pump and supplies various parts of the works with water. The tank can be promptly cut off from the system of fire mains when the fire pump is in operation. The pump supplying this tank, which is situated in the centre of the works, can be used for fire purposes, and fire valves are provided therefor. Fourteen internal fire valves are provided, each having a sufficient quantity of hose and branch pipe in close proximity. Buckets, chemical extinguishers, hand pumps, etc., are distributed throughout the works where necessary.

The fire station—36 feet long, 25 feet broad, and 15 feet high—contains one steam fire-engine of double-acting vertical type of 300 gallons capacity, kept in readiness for instant use; also a hose-cart, manual engine and ambulance-cart, 1,000 yards of hose, eight stand-pipes, twelve branch-pipes, scaling ladders, fire ladders, lamps, and a complete set of minor accessories, such as smoke-jacket, nozzles, etc. A constant supply of hot water is kept, and all engines are arranged for manual or horse draught. The fire alarm consists of a steam whistle of the syren type, and is controlled from the outside of the fire station. At night time a red electric light is also displayed when the alarm is sounded. A sub-station is situated at the opposite end of the works, and contains hose, stand-pipes, branch-pipes, hand-pump, buckets, ladders, etc. A coal supply for the steamer is also kept at the main fire station and near the sub-station.

The fire brigade consists of thirty members, inclusive of officers, and is divided into sections of five men, each in charge of a foreman. One section has the control of the pumps, water and steam supply, in case of fire. The brigade is uniformed, and all members live on the firm's property, or in close proximity to the works. All drills are remunerated and take place fortnightly. Twelve members of the brigade keep their uniforms at the station, the remainder at home. Every month these twelve men are changed. The brigade also attends fires in the district when required.

The works ambulance corps is composed of members of the fire brigade. All fire apparatus throughout the works is cleaned once a week. All fire

valves and hydrants are inspected and tested weekly. Written weekly reports are made concerning the good maintenance and condition of all appliances connected with the fire protection of the works.

Steam is kept up day and night throughout the year. Night watching is performed by a night watchman. Two firemen, an engine-man, and a night watchman are always on the premises during the night and on Sundays."

Some substances when on fire are not easily extinguished by water, and extensive fires of such materials require special modes of dealing with them. The noxious character of the products of combustion proceeding from most chemical substances is a matter also that requires some consideration, as the work of the fire-brigade is much impeded by such circumstances, to say nothing of the danger to life which might possibly ensue. For fire-extinguishing appliances to act properly, they must be entirely in the hands of a trained staff, to be inspected and put into actual use at short intervals, otherwise most surely will they be found unworkable on the occurrence of a crisis. In large works a fire-engine will be found necessary, and in such matters Messrs. Shand Mason and Co., of Blackfriars-road, London, will no doubt be willing to give more practical advice than the author can give.

Hygiene. — Under this head come several subjects that should not be overlooked in the establishment of a works. First and foremost is the supply of potable water of good quality, and without the quality is absolutely above suspicion, it should be filtered. The Berkfeld main service filter is good enough, but it must be placed in charge of some person whose duty it is to see that it is periodically cleansed. In some works oatmeal is provided for the men during the summer months, which is infused in the drinking water, and proves a safe and palatable beverage. The supply of potable water may be based on a consumption of one quart per man per day, and the quantity of oatmeal allowed should average about half-a-pound per man per week.

In this connection the provision of a decent room in which the workmen may eat their meals and deposit their excess clothing while at work should not be deemed unworthy of consideration, and yet in how many chemical establishments do we find any provision whatever made for either of these objects? On the Continent not only are the workmen's clothes cared for while they are at work, but a *cuisine* is often part of the establishment, whence the employees can purchase plain fare at cost price, or even below that figure. One of the best regulated establishments of this kind the author has seen, was that of Messrs. Meister Lucius and Brunning at Höchst, which left nothing to be desired. It is also stated that similar advantages are obtainable by the workpeople at Messrs. Lever Bros.' soap works at Port Sunlight, in Cheshire.

In many works, what are known as steam kettles, steam ovens, and steam hearths, are introduced for the convenience of the workpeople, and the practice is one that should be extended. Messrs. W. H. Bailey and Co., Ltd., of Salford, are large makers of these appliances, and their catalogues are worthy of perusal.

As to sanitary appliances generally, there is plenty of room for improvement. The chemical worker has often been accused of being rough and ready, but he is what his surroundings have made him, and the result of nearly a century of neglect cannot now be undone in a day. One thing to remember, however, in laying out such sanitary work, is that the waste water and sewage will require connecting to a public sewer, and if this be impossible, the sewage will have to be treated before it is allowed to flow into any watercourse. The bacterial system will most probably be adopted, and judging from the experimental plant at Sutton, in Surrey, a bed with 186 square yards of surface (14 yards square), and 5 ft. deep, would suffice to purify 20,000 gallons of sewage daily. In some works lavatories are provided where workmen may indulge in a good wash on leaving their daily work, and in others there are both lavatories and baths. Strong enamelled fireclay-ware can now be had for these purposes, but if common report is to be trusted, it is the bather who is conspicuous by his absence. There must be a reason for this, and it is the author's opinion that the failure is due to a neglect of those little details that make such operations comfortable and enjoyable. It was only in November 1901 that the author was visiting a works where provision was made for bathing, and the manager was complaining of the paucity of bathers. Upon examination, the bath (of enamelled iron) was set upon a concrete floor, the temperature of the room at the time of the author's visit was 33° F.—ice-cold water was in the cistern above the bath, and the water supply to the bath was a piece of three-quarters leaden pipe. Within a few yards from this spot, two steam engines were blowing their exhaust into the open air, and no one had thought of using the waste steam for taking the chill off the water, or of warming the atmosphere of the bath-room, though both things might have been done at the cost of a few lengths of steam pipe.

There are certain occupations in which the workmen become more or less dirty by reason of their employment, and it is hardly right to saddle the wives and families of such men with the inconveniences of personal cleansing. Moreover, most cottage houses are not built up to the standard of personal cleanliness, though some few may claim exemption from such a sweeping charge. It stands to reason that workmen should be enabled to leave the factory with their bodies in a cleanly condition, if they so desire it, but this will be practically impossible unless the lavatory and bathing accommodation is of ample extent, and methodically arranged and managed.

Ample facilities for washing the hands and face should be provided in all industrial establishments. There are many firms making sanitary appliances, lavatory basins and sinks, of very varied sizes and types, but so varied are they that the author feels constrained to omit all notices of them, and to advise would-be purchasers to apply for makers' catalogues. The Factory Acts now take cognizance of such details, so that the Rules and Regulations of the Local Government Board should be studied by all those who intend to fulfil their obligations in such matters.

With reference to baths and bathers, it may be taken for granted that the ordinary dip-bath is not the best for use in ordinary factories. As a rule,

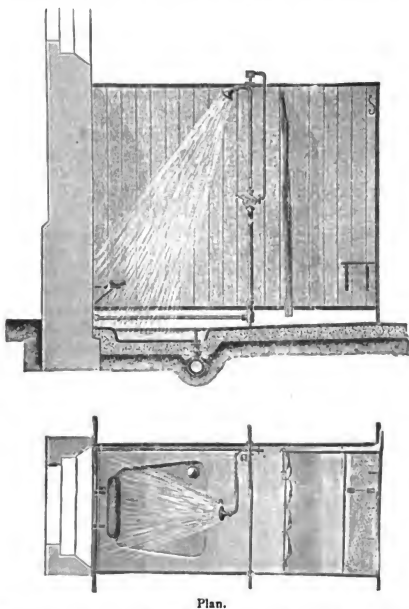
they require cleansing after use by each bather, consume time in filling and emptying, and use a large quantity of water. The best contrivance is the warm-shower cubicle, in which the operation is quickly performed, the consumption of water much less than in a dip-bath, and the bather is at all times being rinsed with fresh water.

The heating of the water is the most important part of the whole business, and next to that is the temperature of the bathing room itself. A man in good health will enjoy a bath of lower temperature when the bathing-room is warm, than he would were the water warmer and the room colder. The hot-water arrangements require to be very carefully devised, especially in the direction of preventing the use of excessively hot water, which might possibly lead to cases of scalding. The hot-water may, of course, be drawn from an overhead supply tank at the temperature required, at any degree from 70° F. to 90° F., which would have to be adjusted to the nature of the occupation and the wishes of the workmen themselves, but there are several appliances that will raise the temperature of the water to any degree the bather may prefer, such as the mixing chambers of Messrs. Doulton and Co., of Lambeth, or the counterflow water-heaters of Messrs. Andrew and Suter, of 23, Goswell-road, London. When steam is employed to heat the water in such appliances as the foregoing, it should be under complete control, and this may mean, perhaps, the introduction of a reducing valve, such as is shown on p. 298, of Vol. I. The thorough ventilation of the bath-house should not be forgotten, as, with water at 80° F., or 90° F., or even hotter, the atmosphere will soon become saturated with moisture, and bring dampness to clothes, rust to iron, rot to woodwork, and wet everywhere.

The warm-shower cubicle, as made by Messrs. Andrew and Suter, may be seen in section by Fig. 244 and in plan by Fig. 245. The number of cubicles required for any definite number of bathers per hour may be arrived at from the following figures, and the space required for the installation may likewise be reckoned out. The inside measurements of the cubicles should be 4 ft. wide and from 6 ft. to 8 ft. deep from back to front, a waterproof curtain hanging across on a galvanised iron rod to protect the dressing portion of the cubicle from the spray. The floor should be made of concrete, skimmed over with neat cement, and a wooden grating laid upon it for the protection of the bathers' feet. The average time the cubicle is occupied by the bather is eighteen minutes, the shower occupying six minutes, during which time nine gallons of water have been used.

It is very seldom indeed that the temperature of a bath is needed over 100° F., and this being the case the fittings for factory bathing rooms should be so constructed that it is impossible, *under any conditions whatsoever*, to heat the water above this temperature. When the medical man prescribes a warm bath, a temperature varying from 96° F. to 104° F. is implied, but for ordinary washing purposes day-by-day it is not necessary nor advisable to touch these temperatures. Tepid water ranging from 85° F. to 95° F. is most suitable for factory bathing establishments, and perhaps 90° F., corresponding as it does with the thermal zone,

surrounding the skin of a clothed person, would be the best temperature to adopt as a standard. A cold bath implies a temperature of the water of 70° F. or below; 50° F. is very cold, and not enjoyed, or even bearable, by any except in the most robust state of health, and even then the period of immersion or subjection to its influence must be of short duration. For an industrial bath-house, then, it seems most natural to secure a



Plan.

FIGS. 244 and 245.—THE WARM-SHOWER CUBICLE FOR FACTORIES.

temperature for the spray capable of variation between 70° F. on the one hand, and 90° F. on the other—the actual cleansing being effected with water at the higher temperature, winding up the operation by a few seconds' exposure to water at a temperature just above 70° F. This should be practically possible with an adjustable counter-flow heater, planned to work between these two extremes. Tepid baths do not excite the nervous centres, they do not affect the circulation, the pulse remains unaffected,

and the temperature of the body remains unaltered, and finishing up for a few seconds with a cold douche produces a healthy reaction, which prevents the bather taking a chill on going out into the air when the bath is over.

Accidents.—A very pertinent question may be asked at the outset—What is an accident? and the reply is by no means so simple as it first appears. Under normal healthy conditions, accidents should be infrequent, and the reply to the foregoing question may be comprised in the words—Accidents are the results of unforeseen circumstances. But this does not dispose of the question, as we have a right to inquire whether the circumstances were unforeseen through neglect, from imperfect knowledge, or from errors in judgment, and these conditions, whatever they may be, serve to enlighten us as to the exact meaning of the word “accident,” and its application to actual facts.

The word “accident” is often employed in a very limited sense—were a workman to fall into a well, or into a pot of soda-liquor, or to receive injuries through the breaking of a rope, there would be no hesitation in describing the circumstance as an accident; but if an illness be brought on by lack of ventilation, or insanitary surroundings, it would seem to be a stretch of the imagination to place such circumstances in the same category. And yet why should it be so? The existence of bad ventilation should be just as well known as the presence of the well; and of insanitary conditions as a bad rope, but perhaps the true explanation of the difference is, that the effects of what are usually termed accidents are acute, while the debilitating effects of chronic injury are to a great extent neglected. Thus it might be an accident if a workman were to swallow a poisonous dose of sugar of lead, but in ordinary parlance it would scarcely be called an accident if a pottery hand succumbed to lead poisoning which had taken twelve months to complete its deadly work. It is an accident nevertheless.

The panacea for accidents of all kinds should be, in the first instance, a desire for healthy work, a full knowledge of the individual conditions of work on the part of the masters, and of the conditions that lead up to accidents, while the workman must be earnest in his desire to co-operate with those in authority in preserving discipline, and in securing the due carrying out of rules and regulations devised for securing the immunity of the worker from such consequences as have already been noted.

Normal conditions, good organisation, good discipline, with an ordinary amount of carefulness on the part of the worker, are the points necessary to ensure comparative freedom from accidents; while rapid work, the want of organisation and discipline, together with inattention on the part of the workman, are just the conditions necessary for a plethora of accidents. And here it may be noted that the ventilation of workshops, the heating and lighting of them, or what is the same thing, their general sanitation, are of the greatest importance; a workman benumbed by cold, or exhausted by heat and steam, or drowsy from the effects of carbonic acid gas, or carbonic oxide gas, may not have sufficient energy to “put his best foot foremost” in a case of emergency. Every worker, no matter in what calling he may be

found, will, at some time or other in his career, find himself in a critical situation, and it is in such times that one learns the necessity of being able to do the right thing at the right time. When this is done, the crisis is averted; when it is not done, the result is an accident. How necessary is it then that full knowledge of these things should be available to everyone concerned.

In the chemical and allied industries, accidents may be either of a mechanical or a chemical nature; cuts, burns or scalds, or even broken limbs fall into the first category, while dust-poisoning, skin-poisoning or gaseous-poisoning come under the heading of the second. There are now several text-books dealing with the "First-aid" treatment of mechanical accidents, and the author would call the reader's attention to one named "First Aid to the Injured and Sick," by Messrs. Warwick and Tunstall.* The prevention of accidents, however, should exercise the ingenuity of the management, much more than the treatment of them, after such have happened. All moving parts of machinery should be securely fenced off, on every side to which workmen have access. The annual report of the Chief Inspector of Factories and Workshops for 1903 is not pleasant reading. It contains the startling information that, during the year, no less than 92,600 accidents occurred, of which 1,047 were fatal. To the credit of the chemical trades, but few of these accidents took place upon their premises, it being the users of chemicals and not the makers of them who have so little reason for congratulation. We hear of accidents daily in the public press, and though many of them appear to be due to carelessness and recklessness on the part of the workman, there are many of them where the balance of evidence is against such a supposition. Many accidents arise from attempts made to shift belts from pulleys while in motion. Is this necessary? Then again, another serious source of accident, is the neglect of common precautions in the starting of machinery and other appliances. The author has read of steam being turned on to men while working in enclosed boilers, of hot gases being turned on to men while working in flues, and even while writing these notes a newspaper paragraph records a "mishap" in the following words:—"A mill hand, in the service of the ——— Mills, found some screws loose in the fulling stocks he was tending, and went inside the machine to see what was wrong. Someone, not knowing he was inside, started the machine, with the result that the man was badly crushed, and has since died at the ——— Infirmary." Surely such "accidents" as these should never be possible.

When an accident has occurred in any factory, it should always be possible to render "first aid" from the home ambulance corps. It is surprising how little the average man knows of first aid, the tendency being to hold aloof, or to do nothing more than wait for the appearance of the doctor. In every chemical and allied works, a special ambulance corps should be organised, and be regularly instructed in first aid methods, but of course it should be understood that in every serious case medical assistance should be solicited at the outset; "first aid" is first aid only, and is not

* Bristol: John Wright and Co. 1901.

intended to supplant the more skilled surgical advice of the medical attendant. A well-trained ambulance corps ensures prompt and efficient attention, which, in most cases of accident, is "half the battle," and ensures the absence of bad and erroneous treatment, to which many victims have been subjected in days gone by.*

The average man's knowledge of extemporised surgery, small though it be, may be extended by reading Messrs. Warwick and Tunstall's book already mentioned, but the practice of first aid cannot be familiarised by mere reading, and requires considerable practice to have the various operations at one's finger ends. There is, too, a certain amount of anatomical information that one stands in need of in emergencies of this kind.

Of the purely mechanical accidents, such as the results of belt-shifting, accidents by means of hoists, cranes, chains and ropes; contusions, cuts, broken and amputated limbs, etc., the author has but little to say, as they are comparatively rare in chemical establishments, but scalds and burns are perhaps more frequent in this class of works than in any other. Of the burns and scalds, we have those in which the temperature of a non-corrosive medium is the disturbing element, and, as a rule, such accidents are serious, as more often than not the surfaces involved are extensive. A fall into the hot brine of a salt-works for instance has always terminated fatally, but the author has known of several cases of severe scalds with hot soda-ash liquor from which the victims have recovered. There are, however, scalds and burns by corrosive substances which are sometimes of a very distressing character, such as are produced by boiling oil of vitriol, or caustic soda solutions.

With cold sulphuric acid, there is not much harm done by contact with the flesh, provided the acid be wiped off immediately, and the spot deluged with water, or even a weak acid, but prolonged contact with strong acid will destroy the cuticle and flesh most assuredly. Hot and strong sulphuric acid is a fearfully corrosive substance, and the burns or scalds produced by it require very careful handling. In all places where hot and strong sulphuric acid is manipulated, there should be kept a box filled with *oxide* of magnesia (not the carbonate) always handy at a moment's notice, by the simple raising of a hinged lid. A splash of hot vitriol must be treated with magnesia *instantly*, if severe corrosion is to be avoided. Caustic soda scalds or burns are usually severe on account of the corrosion, and it is difficult to say without seeing the wound what the nature of the treatment should be. Weak acetic acid is often useful in neutralising the corrosive effects of the alkali, but it must be employed with circumspection. Hot carbolic acid, hot acetic acid vapour and several organic compounds are very unfortunate substances when in the wrong place, as well as a host of other substances that will have to be passed over here, the author's desire being to find that the noxious properties of the various substances made and used in each works have been studied by the chemist in charge, and that the management has issued in pamphlet form for the use of the employees, whatever information is available.

* Factory Act Report, 1903, p. 72.

In connection with the subject of burns and scalds, the action of heat upon the body deserves careful attention. The temperature of the body in health is 98.6°F. (37°C.), but it is not constant throughout the twenty-four hours, fluctuating about 2°F. during that period. The temperature is lowest between 2 a.m. and 6 a.m., gradually rising until the maximum is reached between 5 p.m. and 8 p.m. When the body is exposed to a moist heat, the temperature rises, which is the reason one cannot bear a vapour bath at even a temperature of 120°F. ; but some can carry on work in a dry heat of 130°F. , or even up to 160°F. , as the temperature of the body is kept down by surface evaporation, and by the exhalations from the lungs. If the temperature of the body rises 10°F. to 15°F. above normal it is nearly always fatal, as the proteids of the nervous and muscular system commence to coagulate at 116.6°F. (47°C.), and even at a lower temperature if the exposure be prolonged. External heat acting upon the body, especially when under the influence of fatigue and moisture, will often seriously disturb the heat-regulating functions of the nervous system. In cases of heat stroke, it is common to see the temperature of the body rise to 108°F. (42.2°C.), and even higher than this.

The treatment of burns and scalds, as well as the treatment of injuries received by contact with electric currents, may be found described on pp. 179, *et. seq.*, of Messrs. Warwick and Tunstall's book on First Aid already mentioned. It perhaps should be mentioned here, that extensive burns, even though superficial, may be a source of immediate danger to life. This may often be met by keeping the patient immersed in hot water at 105°F. , but such treatment should not be adopted except under medical advice, but in cases where it would probably be required, time would be saved in getting the water heated, and a few moments may mean everything in such a contingency.

Amongst the accidents one meets with occasionally, are those cases of industrial poisoning which may be placed under three heads:—

- (1) By imbibing,
- (2) „ inhaling, and
- (3) „ surface contact.

Under the first head, we read of such accidents as “the plumber's boy drinking vitriol by mistake from a stoneware ginger-beer bottle”; again, “a workman drinking carbolic acid from a similar containing vessel.” Accidents such as these arise from the reprehensible practice of using as containers for poisons and corrosive substances vessels which, from their very form and popular use, seem to stamp them with a guarantee of innocence.

The poisonings occurring under the headings 2 and 3 are usually the chronic results of chemical uncleanness; the second arising from dust given off from some process or another, while the third results from direct personal contact with poisonous substances or solutions, and both these are illustrated by the white-lead industry, and by the application of lead glazes to pottery. Accidents arising under the first head must be treated *instantly* whenever corrosive substances are in question, as, otherwise, there is very

little hope of saving the life of the patient. The evils arising from the inhalation of poisonous dust may be minimised by the use of suitable respirators, of which more will be said anon, while the chronic effects of poisonous substances, either liquid or solid, may be nullified by the use of frequent ablutions, and by wearing thin india-rubber gloves whenever the substance requires to be much handled. The employment of these india-rubber gloves is a matter of some moment, and when poisonous solids have to be handled or the hands frequently immersed in poisonous liquids, their use should be made imperative. It should be pointed out here, that when rubber goods, towels, etc., are supplied to workmen at the works' expense, there must be some system in dealing them out and looking after them during use, otherwise a heavy expense will be incurred. It is the careless, slovenly and dirty worker who requires to be protected against himself, and if he has proved to be careless and slovenly in his own interests, how can he be expected to be careful and economical in his employer's interest?

Gaseous Poisoning.—Accidents caused by breathing dangerous gases and vapours are by no means uncommon in chemical works, and in allied establishments. Some gases are of so irritating a nature that the workman usually flies from the spot before he has inhaled sufficient to do serious injury; but there are others so insidious that damage is always done before the workman is aware of it. Some men are prone to boast their ability to withstand the influence of these gases, but they should be taught once for all, that no human being, nor animal of any kind, can withstand the influence of gases of the carbon monoxide type, or the sulphuretted hydrogen type. In every works, the ambulance corps should deal with all cases of gaseous poisoning, which, if treated promptly, in the correct way, would yield a much smaller percentage of fatalities than is now unfortunately the case. The ignorance manifested concerning the nature of some of these gases, and the means of resuscitation when they have been inhaled by workmen, led the proprietors of the *Chemical Trade Journal*, in 1896, to draw up a series of regulations and instructions for the prevention of fatal results. These regulations were published in that journal on October 24th of that year, and much information relating to that subject was afterwards issued in pamphlet form. A large "poster" was also devised for hanging up in a prominent place in the office, laboratory or works. This "poster" is given in reduced facsimile on page 515, and it is hoped that its dissemination in the various works where "gassing" accidents are likely to happen may lead to fewer fatalities. One thing is quite certain, that gassing accidents require treating with absolute promptness, and upon the spot. Waiting for the doctor, or removing to a hospital for treatment, means, in all probability, that a life has been sacrificed. We may now consider seriatim some of the gases and vapours which have at one time or another produced fatal results in chemical works and allied establishments.

Carbon monoxide.—This gas, called also carbonic oxide, is perhaps the most dangerous with which one has to deal. It is a constituent of all forms of producer gas, of modern coal-gas, and is present in the working atmosphere of all those metallurgical operations in which the evolved gases

are not taken away directly by means of a flue or chimney. Owing to the extension of gaseous firing, and to the production of gas for gas engines, etc., accidents with carbon monoxide have been very frequent, the report of the Chief Inspector of Factories for 1903 containing much food for reflection. Water-gas contains about one-half of its volume of carbon monoxide, Dowson-gas, Mond-gas, or ordinary producer-gas containing from 12 per cent. to 24 per cent. Modern coal-gas also contains a large proportion of carbon monoxide, due to the admixture of water-gas with the ordinary old-fashioned coal-gas. Producer-gas is often conveyed about the works, wherein it is made and used, in brick flues, through which there is much leakage, and such flues are dangerous elements, if they approach too near to dwelling-houses or offices. In the year 1875, at short intervals, several horses died mysteriously in the stables of a large glass-works in St. Helens. At first they were supposed to have been maliciously poisoned, but upon investigation it was found to be due to an escape of producer-gas from a brick flue which ran under one corner of the stables. Such "accidents" as these do not as a rule become public property; if they did, it is probable that many human lives would be saved. In the year 1904, what was practically a similar accident occurred at a large iron-works in Yorkshire. Two mechanics were found dead in the weigh-cabin of the works, on each side of which ran the flues, which were bricked and flagged over and to all appearances in good order. Ten days later, a lad of fifteen was found dead in the foundry office of the same works, about twenty yards away from the aforesaid weigh-cabin, and fifteen feet away from the flues. It is, therefore, proved that brick flues are not safe conduits for gases, and that when the gases are dangerous a great responsibility rests upon those who use them so.

In the report of the Chief Inspector of Factories already alluded to, a case of gas-poisoning is quoted from Salford. Early in the morning seven females "fainted" in the rooms immediately over the engine-house, the plant working on the Dowson principle. The inspector recommended that the engine-house should be thoroughly ventilated, that notices be posted up explaining the deadly nature of the gas, and that a cylinder of compressed oxygen should be kept on the premises. It is also mentioned in the same report, that in a Burnley cotton weaving shed, ten females were overcome and rendered insensible by an escape of water-gas supplied by the Corporation, and while the said report was in course of preparation, news came in of another "mishap" from Burnley in which eight females were similarly affected. It appears to the author that the introduction of the "suction producer" will probably lead to an increase in the number of "accidents" due to carbon monoxide poisoning.

The first symptoms of poisoning by carbon monoxide are—a general languor, followed by giddiness, weakness and palpitation of the heart, sensations of heaviness in the head, noises in the ears, oppression in the chest, drowsiness and dilated insensitive pupils.

From personal experiments, Dr. Haldane came to the conclusion that 0.05 per cent. of carbon monoxide in otherwise normal air, produces distinct toxic symptoms in man, that 0.2 per cent. causes urgent symptoms, while

one per cent. is usually regarded as a fatal mixture. Air containing 4 per cent. or 5 per cent. of carbon monoxide rapidly causes death, but a one per cent. mixture is quite as fatal if the inhalation is continued long enough. The poisonous properties of carbon monoxide are due to the fact that this gas displaces the oxygen of the hæmoglobin of the blood, forming carboxy-hæmoglobin, which is a fairly stable body, though it will part with its carbon monoxide in pure air, and still more quickly under the influence of oxygen. Death usually occurs before the whole of the hæmoglobin is converted into carboxy-hæmoglobin, but recovery is possible if there is enough free hæmoglobin left to carry on internal respiration, until the noxious carbon monoxide is disengaged.

The post-mortem appearances of a fatal case are exceedingly characteristic. The whole surface of the body is more or less light red in colour—almost the colour of a scarletina patient; the blood is cherry red, is fluid, and resists putrefaction for a very considerable time. If some of the blood is diluted with twenty times its volume of water, and an equal volume of caustic soda solution of sp. gr. 1.34 added, a bright red colour is produced, whereas normal blood, similarly treated, yields a dirty-brown colour.

Cases of chronic poisoning by carbon monoxide may occur amongst workpeople occupying ill-ventilated workrooms heated by gas-stoves, or with slow-combustion coke stoves. The early symptoms are head-ache, neuralgic pains, anæmia, with general indications of defective nutrition. It is, of course, necessary that the first step in the course of treatment should be the removal of the contaminating conditions. The only successful way of treating cases of gaseous poisoning, when carbon monoxide is concerned, is by means of artificial respiration, combined with the use of oxygen, but as the carboxy-hæmoglobin is oxidised *in situ* only with difficulty, the efforts of resuscitation should be continued much longer than is necessary in most other cases of gaseous poisoning. It should also be stated here, for the benefit of those who may be unaware of it, that the ordinary "absorption" type of respirator cannot be used in an atmosphere charged with carbon monoxide. The "rescue" type of respirator must be invariably employed.

Before concluding the remarks upon carbon monoxide, mention should be made of the poisonous properties of its combination with nickel, called nickel carbonyl, the essential feature of the most recent process for the manufacture of metallic nickel. Nickel carbonyl has caused several deaths in the works wherein it is manufactured, and it is very probable that the continued inhalation of extremely small quantities of this product will in the long run terminate fatally.

Carbonic Acid.—This gas is by no means so dangerous as the foregoing, though prompt measures must be taken for resuscitation. It is intimately connected with the processes of respiration and combustion, and is often given off in large quantities from many chemical and physiological operations. Carbonates, of course, when decomposed by acids, give off carbonic acid gas, and as the density of this gas is high, it falls towards the ground, and takes time to diffuse. In the open air comparatively large volumes of carbonic acid gas are often disengaged with impunity, even

when workmen are surrounding the apparatus from which the gas is being set free, but such methods are to be strongly deprecated, it being much safer to conduct the gas into the nearest flue or chimney. It is in brewing vats and disused wells that accidents with carbonic acid gas usually take place. Carbonic acid gas kills by suffocating and excluding oxygen, but an atmosphere slightly contaminated by this gas may be inhaled for long periods without causing much discomfort. It has been recognised, however, that in ordinary factories a high carbonic acid content in the atmosphere is synonymous with bad ventilation, and the Factory Acts have decreed that in cotton mills the atmosphere of the sheds must not contain more than 9 volumes of carbonic acid gas in every 10,000 volumes of air. Textile manufacturers have, however, asserted that they accepted this standard in the belief that it could be maintained, but, having spent large sums in the best available appliances for ventilation they find themselves unable to fulfil literally and at all times the requirements of the law. The requirement now demanded by the inspectors, is that the proportion of carbonic acid gas in the shed shall not exceed that in the outside air by more than five volumes in 10,000 volumes. The carbonic acid in the open air varies according to locality and atmospheric conditions, but in the country it is generally 4·6 volumes per 10,000, and in some towns it is about double this.

In connection with chronic enfeeblement by means of carbonic acid, nothing can be more baneful than the process of heating workrooms with gas fires, or open gas flames, from which the products of combustion are *not* taken away by a regular flue or chimney. The author has heard of some gross cases of this practice, so that the following experience may be of some use in directing attention to this baneful method of heating. In the author's laboratory and drawing offices, heating by means of coal fires was discontinued, and gas fires substituted, four of Fletcher's iron fret-work stoves being employed. The stoves were placed in the centre of the rooms, and lengths of pipe sufficient to cool the products of combustion to 140° F. (60°C.) conveyed these products to the chimneys. Before the arrangements were completed, the gas-fitter to whom the work was entrusted represented to the author that he was going "to a deal of unnecessary expense," as there were many offices and workshops that had no chimneys at all to their gas-fires, and, he added confidentially, "they need none." As the installation was admirably arranged for an interesting experiment, the smoke pipes were not connected to the chimneys for the first month, and, three times a day, carbonic acid determinations were made of the atmosphere.

The normal amount of carbonic acid found in the atmosphere at 9·30 a.m. was 7 parts per 10,000, which increased to 9 parts by noon, when no stoves were alight, while by 5 p.m. it had increased to 10 parts. When the stoves were in use, the normal amount before lighting up was 8 parts per 10,000, which increased to 17 parts by noon, with a further increase to 22 parts by 5 p.m. Upon one occasion, in which the wind was in an unfavourable direction for the usual ventilation, and with the stoves burning at the full, the carbonic acid stood at 8 parts at 9·30 a.m., at 22 parts at noon, while by 5 p.m. it had risen to 45 parts. It is needless to add that when

these experiments were completed, the results of which had not borne out the gas-fitter's statement, the stoves were at once connected up to the chimneys, one set with a smoke pipe three inches in diameter and another set with the pipe four inches in diameter; and experience has shown that the three-inch pipe is too small to take the products of combustion from 50 cubic feet of coal-gas per hour. The contamination of the atmosphere of workshops by carbonic acid gas springs from two sources, (1) the respiration of the workpeople, and (2) the combustion of coal-gas. An ordinary workman may be credited with producing six-tenths of a cubic foot of carbonic gas per hour, and each cubic foot of coal-gas will, on combustion, produce about two cubic feet of CO_2 . When the air to be inspired contains two per cent. of carbonic acid gas, it cannot be breathed for long with safety, while Dr. Angus Smith found by experiment that a lighted candle was extinguished by an atmosphere containing 2.5 per cent. of carbonic acid. Carbonic acid is one of those gases with which an "absorption" type of respirator is useful, provided its capacity for arresting carbonic acid gas be accurately determined. In order to ascertain this we should know that the volume of air respired by a healthy man varies from 26 cubic inches to 30 cubic inches per respiration, and that, *when at rest*, a healthy workman makes about 17 respirations per minute. In fixing the capacity of a respirator, it will be safe to allow for the purification of one-half a cubic foot of air per minute, the length of time the respirator is required to remain in active working order determining its cubic contents. The best absorbent for carbonic acid gas is granulated soda-lime, free from dust, and one pound of this will absorb two cubic feet of carbonic acid when only half saturated.

Sulphuretted Hydrogen.—This is another very insidious gas, but in small quantities and well diluted it is undoubtedly harmless, while in larger volumes and in the concentrated form it is most dangerous; the difficulty is—where to draw the line. Unfortunately, continued inhalation of this gas deadens the sensibility of the nasal organ, so that when a dangerous volume or insufficient dilution comes suddenly upon the workman he is unable to appreciate the difference. In fact, after breathing an atmosphere slightly contaminated with sulphuretted hydrogen for a time, an increase in the contamination yields a rather pleasant sensation and a sweetish taste, and the victim is lured into a sense of false security.

Sulphuretted hydrogen is evolved in many processes, and every care should be taken that leakages do not occur in situations where they would be likely to affect the workmen. This gas is given off in large quantities from what is known as the Chance process of sulphur recovery, wherein carbonic acid gas is made to act on sulphide of calcium, but though several workmen have fallen victims, it is the tar-distilling industry that has suffered most from sulphuretted hydrogen accidents. Most of these have occurred during the cleaning out of stills when one condenser has served for two stills, and the gas has leaked through from the working still and has done its mischief before the leakage has been discovered. The Factory Act rules now prescribe that the idle still must be completely isolated, but it would be better practice to make the rule—one still, one condenser.

Sulphuretted hydrogen is now largely used for the dearsenication of pyrites sulphuric acid. In the old form of apparatus, described and illustrated on page 195, an excess of this gas was allowed to escape into the air, the rate of the escape being regulated by the appearance of the current bubbling through a bottle of water; but in the newer forms of apparatus the gas is forced through the acid mechanically, the excess being returned to the exhaust or inlet side of the fan. In this way there is no escape, and consequently but little danger from that source. In dealing with this gas, the workman should be taught that its inhalation in excessive quantities produces giddiness at the outset, and that, when its flow can be controlled, the first thing to do is to shut-off the current, when it is suspected to be present in undue quantity. This is the only safe course to pursue.

The "absorption" type of respirator may be used in dealing with air contaminated with sulphuretted hydrogen, provided the appliance be of sufficient capacity to contain enough absorbing material, which in this case should be soda-lime granulated with hydrated peroxide of iron.

Nitrous gases.—All these compounds are very insidious in their action. They are evolved in many chemical operations, such as the manufacture of "nitrate of iron," certain metallic nitrates, the manufacture of nitro-compounds, as nitro-benzol, gun cotton and nitro-glycerine, as well as several other compounds. Generally, steps are taken in such operations as the foregoing for their absorption, but when vitriol absorption towers are being repacked, or vitriol chambers are being cleaned out, accidents with nitrous gases have frequently occurred. Nitrous fumes may be inhaled for a short time without seeming inconvenience, but beyond a certain point they act suddenly and acutely, and in such cases the results are often fatal. When there is any suspicion of "gassing" from the inhalation of nitrous compounds, careful watching of the symptoms is advisable for several days after the accident. Many cases are known where the workman appeared not to be affected after inhaling nitrous fumes in quantity, but has next day been seized with severe internal pains, death ultimately resulting, although the best hospital treatment was afforded, the symptoms being as of acute pneumonia.

The Rhenish Westphalian Explosives Co., at Troisdorf, has found the use of chloroform to be very effective in treating cases of gaseous poisoning by nitrous fumes, and the regulations which have been drawn up for the treatment of such cases appeared in *Die Chemische Industrie* for July, 1904, as follows:—

"Should anyone inhale nitrous fumes through mishap, the breaking of a nitric acid bottle, or otherwise, care must be taken that he be supplied every 10 minutes with 3 to 5 drops of chloroform, poured into a glass of water from a dropping bottle. For this purpose, a drinking vessel and three dropping bottles of dark glass are placed under a glass bell-jar in the nitrating house: each dropping bottle contains 0.5 gramme chloroform. In case of accident, a start is to be made at once with bottle No. 1, and those in authority are to be informed immediately. According to the German Pharmacopœia, the maximum single dose of chloroform is only 0.5 gramme

—that is, the contents of one dropping bottle. The greatest daily dose is 1·5 gramme, the contents of the three bottles. Three drops of chloroform weigh only 0·045 gramme, five drops 0·078 gramme. The above regulations must be adhered to rigidly; any misuse of the chloroform will be punished, and brought to the notice of the police. It is further to be noted that each bottle is sealed, and that the seal must be removed by cutting before the chloroform can be used."

Arseniuretted hydrogen.—This cannot be called a common source of poisoning, but it is a very deadly gas, and every precaution should be taken to prevent workmen being exposed to its influence. In the annual report of the Prussian Factory Inspectors for 1903, mention is made of two deaths caused by exposure to this gas, the particularly deadly nature of which is not generally recognised. Arseniuretted hydrogen is very liable to be present in the hydrogen generated from commercial hydrochloric acid and zinc, or from ordinary sulphuric acid and zinc, and when hydrogen is generated from such sources, either for lead burning or for filling balloons, this danger should not be lost sight of, as very minute quantities are sufficient to kill. Both the zinc and the acids may contain arsenic, which is the source of the mischief.

Hydrocyanic acid.—Now that the cyanide industry is in an active condition, and several works are in operation producing cyanides on a very large scale, it behoves the manufacturers to study closely the toxic effects—not only of hydrocyanic acid gas, but of the compound cyanide vapours that escape from some of these operations. Fortunately, the odour of hydrocyanic acid is so striking, that, unlike carbonic acid gas and carbon monoxide, its presence is most markedly indicated. It is an odour that should not be trifled with. It is difficult to say whether any form of respirator of the absorption type can be depended upon, to deal with poisonous mixtures of this gas. Hydrocyanic acid gas is certainly absorbed by granulated soda-lime, but more slowly than carbonic acid, while this latter gas liberates hydrocyanic acid from the cyanides of the alkalies and alkaline earths.

Chlorine, Bromine, Hydrochloric acid gas, Sulphurous acid gas, etc.—Very few fatal accidents have occurred from inhaling these gases, as, owing to their exceedingly irritating properties, the workman usually runs away before much damage be done. Moreover, though they are of so irritating a nature, they are not of the poisonous character which marks those gases that have been previously mentioned, so that even after a severe "gassing," when the source of the danger is removed, the workman is usually in normal health again in a few hours after the accident. Chlorine and bromine, especially the latter, are more dangerous than either sulphur dioxide or hydrochloric acid, but, with ordinary care, there should be no fatality to be laid to the charge of either of these four gases. During thirty years' experience with chlorine, the author has never witnessed a fatal accident with this gas, though he has encountered many serious cases of gassing.

There is no doubt but that the best antidote for gassing by chlorine is alcohol, of the strength of proof spirit, administered in small quantities at a

time. A good brand of whisky is not usually objected to as medicine by the workers in chlorine. Respirators of the absorption type are useful for breathing in atmospheres contaminated with chlorine, provided that a suitable absorbing medium be selected, which may be a granulated mixture of ferrous sulphate, hydrate of lime and caustic soda.

The respirators worn by workmen during the packing of bleaching powder consist of many folds of good flannel, tied over the mouth and nose, as shown in the accompanying illustration (Fig. 246). There is no absorbing material, as it is the dust of finely divided bleaching powder that the workman has chiefly to contend with, and not gaseous chlorine, which latter is present, but in very minute quantity, as a general rule. The workmen prefer these "muzzles" to the better looking and more formal dust arresting respirator, and perhaps there is wisdom in their choice.

- *Ammonia*.—Poisoning by ammonia gas is not frequent, as the workman generally has time to leave the contaminated area, but in making liquid ammonia and in the working of refrigerating machines, severe outbursts are not infrequent, owing to the blowing of glands and the fracture of pipes. The best plan for the workman to adopt in such cases is to shut off any valve there may be for the purpose, and leave until a purer atmosphere has been established. If it is absolutely necessary for anyone to enter the contaminated area he should be provided with the sponge respirator, shown by Fig. 249, the sponge of which has been moistened with *weak* sulphuric acid.

Carbon disulphide, Nitro-benzol, Bi-nitro-benzol, Aniline, etc.—There are many organic compounds that cause severe indisposition and even death to the workmen who are daily exposed to their influence. The effects are chronic when the exposure to small doses is intermittent, and acute when large quantities are concerned, and this class of poisonous substances cannot be better illustrated than by reference to above four compounds. Carbon disulphide, continuously inhaled in small quantities, brings on peripheral neuritis as certainly as alcohol or arsenic would, while the result of inhaling large quantities of the vapour means insensibility and even death. The vapours of nitro-benzol and bi-nitro-benzol produce throbbing headaches and vomiting, the blood assuming a dark chocolate colour and losing its power of absorbing oxygen. When nitro-benzol is injected into the veins of an animal, death occurs almost as quickly as with prussic acid. Aniline is a narcotic poison, and acts upon the central nervous system, causing insensibility, convulsions and motor paralysis. It destroys the blood corpuscles forming methæmoglobin, the urine becomes brownish black, and the skin is often the seat of unhealthy looking eruptions. In dealing with organic substances of this type, great care should be taken to avoid the deleterious effects which the vapours would have upon the workpeople. The vessels and



FIG. 246.—THE BLEACH-PACKER'S MUZZLE.



FIG. 247.—RESCUE APPARATUS.—BELT AND ROPE.
(As used by the United Alkali Co., Ltd.)

stills in which they are manufactured require cleaning at stated intervals, and they should be well steamed out, *and cooled*, before the workman is allowed to enter; the table (26, p. 265) will show the effect of temperature on vapour production of several organic bodies.

Rescue Appliances. — First and foremost amongst these appliances is the belt and rope. If the reader will consult the facsimile on page 515 he will find that the second rule of the General Regulations reads: "That no person may go into dangerous places, unless he be efficiently secured round the waist by a rope. A very strong leather belt, with buckle, and a stout rope permanently attached to it would be better, as it could be brought into use instantaneously." Such an outfit is shown in Fig. 247.

It was only on Christmas Day, 1901, that three men at a works near Manchester lost their lives through gaseous poisoning with carbon monoxide. A gas-holder which had contained this gas was in course of removal, and a workman was sent inside by the foreman to cut away some connection with an outside pipe. After a few seconds, the man collapsed, and in the attempt to rescue him two other lives were lost. If the first man entering had been "efficiently secured round the waist by a rope" he could have been withdrawn without anyone else entering the deadly atmosphere, and he would probably, after efficient treatment, have been but little worse for the mishap, or error of judgment of his foreman.

Another important piece of apparatus is a light, efficient and portable air-pump to supply air in abundance to any "rescue" type of respirator which it may be necessary to employ. We have already seen that the minimum air supply needed for active respiration (page 502) for one person is half a cubic foot per minute, and an efficient air pump should be capable of giving ten or twelve times this volume. A blower of the fan type is the best for this work, and care should be taken to provide an air pipe of sufficient diameter, the friction being very great in tubes of small diameter and numerous bends. Reference to Table 77, p. 213, Vol. I., will give some information in this direction.

Where there is danger from fire during a rescue, the provision of asbestos garments is a matter that should receive ample consideration.

Respirators. — Referring once more to page 515, it will be found that a "properly charged respirator" must be worn, and here we must examine what is meant by the three words in parenthesis. Respirators are of three types, which may be classified as:—

- (a) Dust arresters,
- (b) Absorption respirators, and
- (c) Respirators for rescue work.

Respirators of the first type, for preventing the inhalation of dust or solid particles, are generally constructed with sponge, cotton-wool, flannel or felt as the filtering medium, and these answer admirably for the purpose. Their general form and appearance are shown by Fig. 248, which exhibits the appliance made by Messrs. Zimmer and Co., of 82, Mark-lane, London. These respirators are so made that the filtering medium may be taken out and replaced with fresh material whenever necessary, and it should be

thoroughly understood that this type is only suitable for arresting and preventing the inhalation of dust, and is of no use when gases such as carbon monoxide, carbonic acid and sulphuretted hydrogen are concerned.

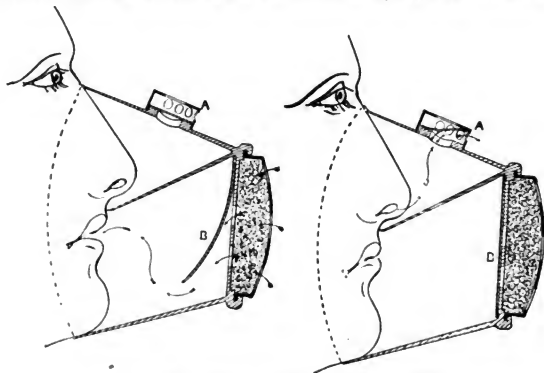


FIG. 248.—ZIMMER'S PATENT VALVE RESPIRATOR.

When made of sponge, however, as shown in Fig. 249, they may be found useful for arresting ammonia gases by squeezing out the sponge from a weak solution of acid, or from water only where the atmosphere is tainted with hydrochloric acid gas.



FIG. 249.
SPONGE RESPIRATOR.

Respirators of the second type, "absorption" respirators as they are called, consist of a reservoir containing material which absorbs and retains the noxious gas, allowing the air with which it is mixed to pass in a pure state for inhalation. Such respirators are useful for carbonic acid and sulphuretted hydrogen, but are not of the slightest use for carbon monoxide, as this gas is not absorbed by any known practical reagent. It will be at once evident that the capacity of the reservoir holding the absorbing material must bear a definite relationship to the time the respirator is desired to remain in active operation, and that means must be provided for preventing the accidental inhalation of the poisonous gas. Mr. Towers, of Widnes,

supplies this type of respirator in two sizes, taking the form shown in Fig. 250. The larger size will keep a man safely in an atmosphere containing ten times

the minimum poisonous quantity of sulphuretted hydrogen for six hours, or in one hundred times the poisonous strength for forty minutes. The smaller size is about one-half of this efficiency. The illustration shows roughly the construction of this type of respirator, which consists of a reservoir C filled with the solid absorbent, and connected by the flexible tube T to a mouthpiece fitted with automatic inlet and outlet valves. The air enters by the opening O, and passing downwards through the absorbent is filtered through cotton-wool in the chamber F and conveyed through the flexible tube to the mouthpiece M. The exhaled air escapes through the exit valve E. A nose-clip N for the prevention of accidental inhalation through the nose is attached to the mouthpiece by a small chain, and the plug P closes the inlet at O when the respirator is not in use, and at the same time serves as a convenient support for the mouthpiece. It should always be remembered when working with absorption respirators, that owing to the difference in sensitiveness between the mucous membrane of the nose and that of the throat, it is possible when the nose is closed to inhale a dangerous quantity of gas without being aware of it until the damage is done. This happened to the author on one occasion when experimenting with a respirator of new pattern.

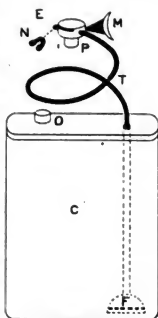


FIG. 250.
ABSORPTION RESPIRATOR.

The third form of respirator is known as the "Rescue" type, and may be used under all circumstances, and for all poisonous gases. There are many cases where even the second type, or absorption pattern, cannot be considered safe, as no knowledge can be obtained quickly of the degree of concentration of the poisonous gas, to say nothing of those cases in which it is known with certainty that the whole atmosphere is absolutely irrespirable. Further, in rescue work, the rescuers have often to remain for long periods in very bad atmospheres, so that it is necessary to place beyond doubt the reliability of the protection afforded to the workers.

The safety respirator made by Messrs. Zimmer and Co., of London, consists of a hood, brought together round the neck by a girdle, as shown in Fig. 251. It is supplied with air in excess from an air-pump through a length of flexible armoured



FIG. 251.
ZIMMER'S SAFETY RESPIRATOR.



FIG. 252.
THE PNEUMATOPHOR.



FIG. 254.
ZIMMER'S RESCUE
APPARATUS.

india-rubber tubing, and as the air is always supplied in considerable excess, the products of respiration are readily carried away.

Messrs. Wallach Bros., of London, are also vendors of safety appliances generally, one of their specialties being the "Pneumatophor," shown by Fig. 252. It is a light and exceedingly simple appliance and worked in connection with a cylinder of compressed air or oxygen, but is not so generally useful as those forms that are worked with an unlimited supply of fresh air.

Messrs. Zimmer and Co. also supply an aluminium helmet, shown by Fig. 253, weighing about 14 oz., which can either be used in conjunction with an air-pump supply or a cylinder of compressed oxygen or liquid air. When employed with the latter adjuncts a cylinder is supplied with all necessary reducing apparatus, as shown by Fig. 254.

The principle upon which this class of respirators acts, is that of shutting out the contaminated air from contact with the respiratory organs and supplying pure air from the outside, or from a bottle of compressed gas carried by the wearer. For most purposes it is desirable that respiration should take place by either mouth or nostrils at will, as if the nose is closed there is a sensation of shortness of breath, which during violent exercise is distressing, even if it is largely imaginary.

The face-piece devised by Mr. Douglas Herman for this class of respirator is shown in Fig. 255. It has been put through a number of tests and trials, in addition to which, it may

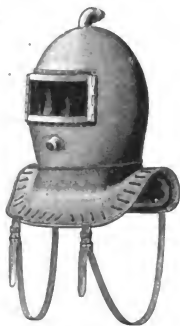


FIG. 253.
ZIMMER'S ALUMINIUM
HELMET.

be pointed out, that by wearing one of these appliances a man has worked with safety for twenty minutes in a hot flue full of producer gas, and, considering the surroundings, without inconvenience.

It will be seen from the illustration that the edge of a cone-shaped body is protected by a pneumatic cushion, readily inflated by the mouth and closed with a small plug of glass rod *a*. By means of a buckle and strap passing round the head the "plate" is held firmly in position on the face, to the contour of which the pneumatic cushion sits closely and easily. The supply of air enters through *b*, while the exhaled products of respiration escape through the valve *c*. This valve is very simple and ingenious. A metal "pill-box" perforated at its lower edge and on the lid is closed by an ordinary cork with a hole in the centre to fit over a short pipe projecting from the body of the mask. Prior to closing the mouth of the "pill-box," a disc of mica is inserted. When in position this combination acts as a clack, or grid valve, the mica disc rising with pressure from within, but sitting air-tight on the smooth surface of the cork under the external pressure exerted during the inhalation through *b*.

A rescue respirator of similar type as sold by Mr. Towers is shown ready for action by Fig. 247, which represents a workman equipped ready for going into dangerous situations. The belt and safety rope are seen upon him, while the respirator is connected up to the pure air supply by the length of the india-rubber tube shown in the foreground.

The Oxygen Bottle.—This can be briefly described here, though the next section covers much of the ground. It is highly desirable that the oxygen should be as pure as possible, and as that prepared by Brin's process has stood the test of practical and medical use, preference is given to it. The Manchester Oxygen Company, and the related branch companies who make it, have specially provided a cylinder of convenient size, charged with gas, and fitted with a regulating valve capable of fine adjustment. Fig. 256 shows such a cylinder, with its stand and valve complete. In the next illustration (Fig. 257) the details of the valve fittings are shown. A comparison of the letterings will explain the illustrations at once, N being the oxygen outlet. The lettering also refers to printed instructions which are supplied by the Company, explaining the method of connecting the fittings. Minor details of the connections may vary a little when supplied by branch companies, but the general design is the same. When in use, the key K is turned once or twice, and the supply regulated by the valve handle T.

When oxygen was first proposed as a restorative agent, some persons were very dubious as to its value, but there are none of these unbelievers at the present time. In order to test the efficacy of oxygen as a restorative

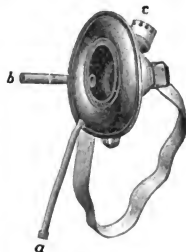


FIG. 255.
MR. DOUGLAS HERMAN'S
FACE-PIECE.

in cases of gaseous poisoning, Dr. Haldane subjected himself to the gas of "after-damp," which contains both carbon monoxide and carbonic acid. His experience showed that a miner does not receive any warning of his danger in breathing this gas, until he is practically past helping himself. Dr. Haldane continued to inhale this gas for seventy-one minutes; his own record, at this, the final stage being that the blood was very pink, showing 49 per cent. saturation with carbon monoxide; his vision was dim, walking without assistance almost an impossibility, and movement very uncertain. After the lapse of a quarter of an hour from the time of breathing the polluted



FIG. 256.

OXYGEN BOTTLE AND FITTINGS.
(By the Manchester Oxygen Co.)



FIG. 258.



FIG. 257.

atmosphere, he found he could walk again, and following the administration of oxygen all the distressing symptoms terminated immediately. It will thus be seen that oxygen is not only capable of rendering great service, but will act very speedily, even when the blood shows 49 per cent. of saturation with carbon monoxide.

In administering the oxygen from cylinders in which it is so highly compressed, the perfect control of the pressure is of great importance, and it is absolutely necessary to have a proper regulating valve in addition to the usual screw K. In the hands of those who have had experience in dealing with gassing cases, the regulation of the pressure is an easy matter.

It is most simply effected by manipulating the regulating valve R. The pressure regulator shown by Fig. 258 is, however, preferable in some respects. It is so adjusted as to deliver the whole contents of a cylinder at a steady, uniform, and convenient pressure. Its action is automatic, so that no matter how much the cylinder valve is opened by the key K, the pressure will always remain safe and constant, while the flow of gas can be regulated or completely checked by compressing the india-rubber tube between the fingers. There will be no accumulation of pressure to bulge the tube or burst it off the nipple. The rubber tube and glass or vulcanite mouthpiece can be rigged up in any laboratory, and, personally, preference is given to it. The choice of some falls on the face piece or mask, which is provided with a pneumatic cushion, the oxygen supply tube being slipped over the apex of the cone; but the selection may safely be left to those who have been educated to use them.

Resuscitation Processes — The author is by no means satisfied that "gassing" cases always receive proper and suitable attention. Of course it is the easiest thing to "send for the doctor," and it is very easy also for the local medical practitioner to order "immediate removal to the infirmary"; but this cannot be done in a moment, and in nearly every case the time thus occupied would be much better spent in an *immediate* attempt at resuscitation, especially if the poisoning has been due to carbon monoxide. Treatment should be commenced *immediately* after rescue, and hope should not be lightly abandoned, even in cases where exposure to the gas has been of several hours' duration. Much depends of course upon the strength of the gas, but in every case a very prolonged oxygen treatment, combined with lung exercise, or artificial respiration, should be persevered in. Messrs. Warwick and Tunstall's book on First Aid has already been mentioned in connection with accidents of a mechanical nature. Little is said therein on the subject of gaseous poisoning, but a very full account is given of the process of artificial respiration to which the reader is referred for technical instruction. In connection with poisoning by carbon monoxide, the Annual Report of the Chief Inspector of Factories and Workshops for 1903 contains on page 72 evidence going to prove the author's contention that cases of gaseous poisoning do not always receive proper attention. Mr. Hilditch, the North Wales Inspector, relates the following "first aid" given in his district to gassing cases:—

"The case of gas poisoning is interesting as throwing a light on some of the crude methods adopted in resuscitating men overcome by gas. One witness at the inquest [and be it noted that there was an inquest*], in reply to my query, said that they had cases of gassing at the top of the blast furnaces frequently. Asked what treatment followed in cases of gassing, he replied that the man was buried. This burying process was explained as follows:—The patient was carried on to a grass patch a little distance from the furnaces, and placed on his back in a trench made for the purpose. The lower portion of the body was then covered with sods, leaving the head and neck protruding above the trench."

* Author's Note.

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RULES FOR DEALING WITH DANGEROUS CASES.

GENERAL REGULATIONS.

NO person must enter any boiler or tank which has been recently used for the storage of any poisonous liquid or gas or enter any dangerous workings, drain, sewer, culvert, gas purifier, flue, vitriol chamber, or tower (whether closed or open), except under the following conditions :—

1. A respirator properly charged and in good condition *must* be worn. If the gases cannot be absorbed, a safety pipe and face piece supplied with air or oxygen must be substituted, according to the manager's instructions.
2. The person entering must be efficiently secured round the waist by a rope, the opposite end of which must be securely fastened to the ground at the surface, or at the top of the tower or flue, &c.
3. A man must be in attendance and ready to render assistance if necessary. For underground work and in difficult positions *two* men must always be on the surface ready to assist.

HOW TO TREAT WHEN GASSED.

Remove as speedily as possible into the open-air, and place in a well ventilated position near the boiler so as to keep as warm as possible.

IN BAD CASES use the oxygen bottle and lung exercise simultaneously from the outset.

USE OF OXYGEN BOTTLE.

The Bottle must Never be Used without a Reducing Valve.

If Conscious.—Very slightly turn on the valve so that the oxygen flows in a gentle stream. Place the glass tube in the mouth and let the oxygen be breathed until relief is obtained.

If Unconscious.—Place the oxygen delivery tube in one corner of the mouth, closing the lips round it. Keep the oxygen flowing in a gentle continuous stream, alternately closing and opening the nostrils to inflate and deflate the lungs. (Gently pressing the chest when the nostrils are open assists the deflation.)

If the Teeth are Set.—Close the lips. Insert the oxygen tube in one nostril and alternately close and open the other in the manner just described. The complete inflation of the lungs is indicated by the blowing out of the cheeks. The closing of the lips is therefore important. *Carefully avoid too great a pressure in the lungs.*

LUNG EXERCISE.

This is not often necessary but if the oxygen does not act within a reasonable time, use the following additional help to respiration:—Lay the body at full length, face upwards, slightly raising the *shoulders* with a folded coat, the head falling well back. Loosen the clothing round the neck and chest. Grasp the arms above the wrist and steadily draw them straight out above the head, holding them there for two seconds. Then turn the arms down, bending the elbows, and at the same time pressing them firmly against the sides of chest, and hold them in that position for two seconds.

Continue this treatment about 15 times a minute for twenty minutes without cessation, or until consciousness is restored.

It is to be hoped that the next time one hears of this method being adopted for the *resuscitation* (?) of a workman gassed with carbon monoxide, it will be when the practisers of the method have been indicted for manslaughter.

As to the correct method that should be followed in all cases of gaseous poisoning, little more may be said than appears in the Rules and Regulations on the preceding page first issued in the pages of the *Chemical Trade Journal*. These instructions have had a wide circulation, and it is hoped that the information so diffused will secure a more rational treatment for future "gassing" cases than those here recorded from North Wales.



END OF VOL. II.

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